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**SCIENCE**  
**IN GENERAL EDUCATION**



# **SCIENCE IN GENERAL EDUCATION**

*Edited by*

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# Preface

Higher education is in a state of ferment. There is scarcely a college in the country which is not at present re-examining its purposes and its program. Already a host of institutions have launched new programs intended to improve the preparation of youth for life in a highly complex and troubled world. Most of these new ventures have to do with general education, that which prepares young people for their common activities as citizens in a free society. Concerning the objectives of general education there seems to be increasing agreement. Wide divergence of opinion still exists, however, with regard to the means that should be employed to reach the desired goals. Faculties are earnestly experimenting in the hope of finding a more satisfactory program of general studies for the needs of their students. Courses of study, teaching methods, examining procedures, materials of instruction—all vary considerably from place to place.

*Science in General Education*, and its companion volumes in other fields, are the result of a conviction that college teachers everywhere are interested in the curricular changes occurring in sister institutions. This conclusion was reached during a series of visits to colleges and universities made possible by the Carnegie Corporation in the fall of 1947. At that time discussions with many teachers of general courses in science revealed an almost universal desire to exchange experiences with other teachers and curriculum planners. Moreover, administrative officers in institutions in which general courses are offered are continuously plied with questions concerning all aspects of these new courses. They welcomed an opportunity to make a public statement about their respective programs to which those who wished information and help could turn. Moreover, conferences of educators in the various subject-matter fields, such as that held at Princeton Inn in December 1947, of scientists interested in general education, have exhibited a desire for cooperative effort in the development of more adequate courses for the non-specialist student.

This volume is therefore an attempt to bring together between the covers of a single publication a set of statements from representative institutions describing science courses for the student who does not intend to devote his life to science or to a related occupation. It presents detailed information about a wide variety of such courses together with discussions of the philosophic principles on which they rest.

Obviously in a venture of this sort an arbitrary selection of institutions was unavoidable. The controlling principle in this selec-

tion was that the institutions or the authors invited to contribute to the volume should have exhibited real interest and effort in the development of courses in science for the purposes of general education. Some of the institutions included, like Chicago and Colgate, have had many years experience with such instruction; the experience of others, like Harvard and Haverford, has been more recent, but each has made a significant contribution to the thinking and the practice in this field. Different types of institutions such as state universities, large private universities, small colleges, teachers colleges, junior colleges, and others were deliberately selected in order that the peculiar experiences of each might be made evident.

Some of the most promising curricular innovations were undoubtedly overlooked in planning this volume. Unique experiments may be under way that should have been included. This collection of statements is not, however intended to be definitive, final, or complete, but representative. It presents descriptions of general education courses in the fields of the physical and biological sciences which are considered by those who have studied the matter to represent significant developments in this field which should be widely known among the profession. It may well be that the publication of this set of statements, presenting quite different designs for science courses for the nonspecialist, will stir up temporarily more problems than it will solve. If such should be the outcome, the effort involved in the project would be justified, for the attention of scientists and educators generally would thus be focused on the difficulties which lie ahead in the development of an adequate program of general education for American youth.

It is hoped, however, that this volume will report the progress already made in overcoming these difficulties in a few institutions for the benefit of those faculties only now beginning to reconsider the aims of higher education for the thousands of students who do not wish to become specialists or scholars in any particular field, but who do wish to gain enough knowledge to make intelligent decisions as citizens. Faculties may thus gain the benefits of successful innovations and avoid the frustrations and waste involved in abortive efforts at curriculum revision. Those who find such help in these statements will owe a debt of gratitude to the many men and women who, though busy with their own teaching and research, have yet considered general education of sufficient importance to give generously of their time in explaining and evaluating their own experiences for the benefit of their colleagues elsewhere. The editor wishes to express his own thanks to the authors of the several chapters and to others who gave valuable suggestions and advice.

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## Science Courses in General Education

MUCH OF the welfare of civilization, and perhaps even its fate, depends on science. Do our science courses educate students to understand this dependence? Scientists have a characteristic way of thinking and planning and working, which we call the scientific attitude or scientific method or science itself, that offers intellectual resources and guidance to all students. Do our science courses send their students out delighted with that understanding of science, and ready to turn it in new directions? Can governors and administrators who have taken our science courses confer intelligently with scientists on the vital problems of our age? In general, does our science teaching in school and college make its proper contribution to general education? Even in the matter of teaching some science, are we meeting students' needs and hopes?

### NEED FOR NEW SCIENCE COURSES

Children are thrilled with the idea of scientific experiments and knowledge. Many a small boy is eager to learn physics and chemistry. When we show him a plain test tube, his tongue hangs out with enthusiasm. He longs to play with the first magnet he sees. Yet a few years of science classes—including, say, some qualitative analysis or a study of magnetic-field formulas—will deaden the enthusiasm in almost all students. A few emerge still determined to be scientists—but even they usually have a strange picture of science as a sort of stamp-collection of facts, or else as a game of “getting the right answer.” For the majority, well-meant teaching has built a wall around science, a stupid antagonistic wall of ignorance and prejudice.

In general education, we need not start the training of professional scientists (that can be done much faster once the vocation is chosen); we need not try to equip everyone with a lot of scientific knowledge (that can be stored in books or

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By Eric M. Rogers, associate professor of physics, Princeton University.

left to the professionals); but we do need to give an understanding of science and its contributions to the intellectual, spiritual, and physical aspects of our lives.

Suppose we think of our own children in college concentrating in economics or languages or history, but taking some science courses as part of their general education. With what questions should we test the "success" of such courses? We should hardly be content to ask: "How many facts have they learned?" Facts are forgotten all too soon. We are more likely to ask: "Can they think scientifically? Do they understand what science is about and how scientists go about their work? Have they a friendly feeling toward science and scientists? Are they likely to read scientific books in later life with enjoyment and understanding? Could they work with scientific advisers in business or government? Could they enjoy intellectual discussions with scientists?" In asking such questions as parents and educators, we betray some of our educational aims. We should not agree on all our aims, but I think most of us have in common a number of aims and hopes which form a cogent group, demanding quite a different kind of science course from the orthodox ones now given in many colleges.

### *Orthodox courses*

The orthodox course—easily named, but really a variable character hard to describe—is useful as the beginning of professional scientific training; but in this discussion it is one of the villains of the piece. For many years colleges all over the world have offered formal elementary science courses to their students, to science specialists and others alike. In most cases, these have grown to be courses in a single science with almost standardized content.<sup>1</sup> Emphasis tends to be on content rather than on ideas or scientific method or even thorough understanding; and the courses are intended to provide a sound foundation for more specialized work in their science. Many nonscientists take such courses, under university rules enforcing "broad general programs" or through their own interests and choice. Colleges have defended the use of such courses

<sup>1</sup>For example, physics texts intended for first-year college courses have almost identical content and much the same order of topics as each other. Each author seems afraid to omit what his rivals include.

for general education on grounds such as the following (I have added a parenthetical chorus of criticism) :

1. A thorough grounding in science gives a good idea of the nature of science. (However genuine this aim, it seems doubtful whether real students find that orthodox courses do this for them. The topics seem to be crowded and unfinished. The teacher seldom has time to point the moral.)
2. An acquaintance with the main facts of a science is itself a valuable part of education for civilized life. (Facts are soon forgotten or muddled, particularly when delivered with authority and speed. If "education is what is left after what you learn has been forgotten," the providing of fact-content should not be the sole aim in science courses for general education.)
3. The discipline of thorough study, including learning material that is boring or difficult, is valuable in itself. (Under criticism from psychologists, this kind of argument has lost favor in the field of classics. In science it is likely to lose favor for the same reason; and it is likely to be crowded out by other aims.)
4. Work in science gives training in scientific method—that is, it makes people more scientific—a virtue to be transferred to other studies and other activities in general life. (This gives a cogent reason for any studies which do provide such benefits. Investigations show that such transfer of training does not occur easily or in great measure. To encourage it, we need to modify our teaching, as we shall see later.)
5. A taste of science in a first college course gives some students a chance to decide they will be scientists. (This is true, particularly in the choice between one science and another; but it may not be necessary to offer the samples in the form of orthodox courses. In any case, one single-science course fails to give students much width of persuasion in their choice.)

#### *Science for the general student*

In discussions of general education, the suitability of orthodox science courses has been questioned, and some colleges have started or are planning science courses which they hope will give greater benefits to the education of the general student. These new courses differ among themselves in schemes of content and teaching and even in their underlying aims. Obviously, differences of aim are likely to lead to differences of

treatment. So at first thought we must settle our aims before we can give such courses. Yet a full discussion of aims would be endless, leading to unresolvable differences of opinion, tangled with educational difficulties rooted in differences of educational social and political ideology. Committees have succeeded in evolving statements of aims, but the resulting lists are too impractical and too long. Yet there are common elements among the aims that different people ask for in science courses for the general student, and I believe that we can make courses that foster such aims. So I shall give only an inconclusive, unscientific discussion of aims, to show our general line of thought.

#### *Aims for general science courses*

Imparting scientific knowledge is common to all science courses, with aims ranging from making healthier citizens to training better soldiers for mechanized warfare. We rely on special courses to give specialized training; but, in general education, while some acquaintance with fact comes anyway, rigorous courses in facts and principles are disappointing. Perhaps we can neglect some of the fact-material now taught; then the rest may profit from more careful teaching so that the student actually remembers more material, not less, some time after the course. Students who have a good understanding of the nature of science should be able to look up facts in books, and are likely to retain a lifelong interest in scientific reading.

So we have come to think that the more important things to aim at in science courses in general education are such things as: understanding what science is about and knowing how scientists go about their work, rather than material knowledge alone. To give such understanding, we must modify the orthodox courses, paying quite a price, in terms of technical training, for the gain we hope to make. So we ask, what are the values to be sought, and how can we construct a course that is likely to give them? When we try to answer these questions, the problem of transfer appears again and again; so I shall discuss that problem before suggesting a list of aims.

#### TRANSFER OF TRAINING

"Will students transfer training, in some skill or habit or the use of some idea, from a science course to other studies or

to life in general?" This is a vital question. If the answer is "no," our new schemes must relate merely to better training inside a science, and offer little promise as a part of general education. If the answer is "yes," our hopes should be grand indeed. In earlier generations, courses in classics, history, mathematics as well as science—in fact most of higher education—claimed cultural values on the ground that their teaching would transfer to many other fields of the student's education and there be retained as part of his general culture. Educators pointed to the high levels of scholarship and culture "produced" by a thorough classical education. In this they seem to have risked some confusion between *post hoc* and *propter hoc*—we might suggest their classical scholars had the intellect and background to succeed anyway. There have been growing doubts about this hoped-for transfer. Are scientists themselves better for their studies: tidy and systematic in their general life, critical and unbiassed in their general thinking?

Since early this century experimental investigations at first said "no" to our question about transfer, then later studies showed that it can occur to some extent. It certainly does not take place as easily as educators and the general public hoped. If it did not occur at all, higher education would seem almost worthless except for special professional training. Fortunately there is some transfer—language teaching can improve intellectual skills, mathematics can give a sense of form or give training in careful argument, and so on—but only in certain favorable circumstances. In our present discussion, it is essential to know what these favorable circumstances are and to try to provide them. They seem to be:

1. There must be common ground between the field of the training and the field to which we wish it to transfer; or there must be similarity between the influencing and influenced functions. For example, if we train a student to weigh accurately in a physics laboratory, it is almost certain that this training will transfer to another physics laboratory and he will weigh the more accurately there; it is moderately certain that he will carry his good training to a chemistry laboratory; much less likely that he will carry it to any weighing he does in his own kitchen or in his business; and it is very unlikely that the training in accuracy will reappear as a habit of being accurate

in other activities. Another example: training in argument learned in geometry is likely to be transferred to later geometrical studies, not very likely to be transferred to work in physics, unlikely to help the student to think critically about arguments in newspaper advertisements, and very unlikely to make him a better economist. (We can lessen the gloomy doubts expressed in these examples by attending to the other conditions 2 and 3.)

2. Generalization, with hope of transfer, should be encouraged. Making a student aware of his gains in one field, and pointing out their applicability to other fields, can make transfer more likely.

3. An almost essential lubricant for the process of generalization is the emotional attachment (or "sentiment") the student develops—the extent to which he associates feelings of enjoyment, interest, inspiration with his studies. The more he enjoys his science and is inspired by its skills and methods, the more he likes discussing its philosophy, the more likely he is to retain and generalize the teaching. Thus, reverting to our examples, a student who develops a *delight* in accurate weighing, making accuracy almost a minor ideal, may well carry the techniques and attitude of seeking accuracy far and wide in his activities, particularly if he has been made aware of the possibility and value of this wide transfer. The student who develops skill in geometrical argument *and* feels inspired by the method may well become the clearer lawyer or cleverer economist by the transfer of some of that training.

4. It has been suggested that ease and amount of transfer increase with increasing general intelligence. This seems reasonable in the light of the other requirements. If this is true, the brightest students should profit most from courses in general education.

#### DISCUSSION OF SOME AIMS

With the difficulties of transfer in mind, we can now review some of the benefits aimed at or claimed in science courses. We can see that an orthodox course full of information, enlivened by demonstration and exhortation, may fail to make any great contribution to general education, and may even fail to educate students in science. In planning new science courses we are

offered a variety of aims. I shall list some of these below, with comments.

### *Scientific method*

The course should teach scientific method, that is, show how scientists attack a problem: gathering data, sorting data, making and testing hypotheses, suggesting and trying further experiments, until theory and experimental knowledge are built into the structure of a science.

I think there are two kinds of aim here: (*a*) training in scientific investigation, both in science and outside and (*b*) showing the student what science is like. The former training would be a fine part of a student's education if we could really equip him to use it, but it is doubtful whether we can train people to behave much more scientifically in their general life. Also, the scientific method may not be so wisely applicable to other studies such as the social sciences. Perhaps the furthest we can hope to go is to encourage a scientific attitude and critical thinking in general life.

In showing what science is like, we can go much further. Orthodox courses try to do this by imparting knowledge of facts thoroughly, but not only do they tend to crowd out the teaching of method and the showing of the nature of science; they also give a mistaken picture of science itself by making it seem to be a body of fact provided mysteriously or known to only a few. However, science courses can be made to show the methods and growth and nature of science, perhaps by historical treatment, perhaps by other methods. But in all cases there must be time for students and teachers to discuss these matters, which should be presented with active attention to their part in the student's education. In a way, the patient needs to be reminded that he is taking good medicine and that if he co-operates he may expect great benefits.

In the teaching of scientific method, we find encouraging critical thinking as one of the aims. Here we may hope for some transfer, but only if we plan for it. We may use the course as ground in which to grow habits of critical thinking. Scientific work involves great care to avoid bias, so it is easy for the student to see the need for logical, unbiased thinking in science. However, we should not assume that mere contact with science which is so critical will make the student think

critically. I think this is an important aim, not easy to achieve—often not achieved in the measure its sponsors claim or hope—to be sought by giving students time to discuss scientific material critically and creatively. Humanists would claim that their fields provide good opportunity too—for example, courses in logic, philosophy, semantics, poetry, history. However, like the scientists, they have spoiled their chances by choking their courses with too much material and they have soured the customers by their preoccupation in examinations with the “detestable testables” such as spelling and dates. The scientists feel that their field provides easy, clear-cut material for this teaching.

### *Creative work*

There is a tendency in modern fact-jammed education to starve students of real creative activity. Many a graduate in science emerges with no memory of creative experience in college. Yet without such experience, civilized man is a dull fellow and general education has little chance to make him better. Students can experience creative work in science if they are given time, opportunity, and encouragement instead of being told, “That was known twenty years ago,” or being instructed, “Do this problem properly, the way the book tells you.” Laboratory work can provide a sense of real creative work for some. Reading, with some free choice, can give it to others. For others, essays and discussions can provide it, but these should deal with thought-provoking questions rather than routine problems. With our interest turned toward it, we can give students a sense of creative activity, and we may hope they will thereby gain in such things as critical thinking.

### *Cultivating general abilities*

This sounds like an educational catch-all, but it is an expression of our general hopes for transfer from science to general education. We may be able to make our science teaching contribute to aspects of general education such as responsible citizenship, effective use of spoken and written language, intellectual curiosity, creative imagination, philosophy of life. We should not push our hopes of such general transfer too far, nor should we spread our aims so widely over these general fields that we crowd out the actual teaching

of some knowledge of science. Teachers and planners should review these general aims before they start and then just leave them in the back of their minds as laudable ideals.

### *Teaching basic principles*

"Understanding of the basic principles of the physical and biological world, their implications for human welfare and their influence on the development of thought and institutions" would seem, at first reading, to be just the kind of aim many of us have in mind. But can we make the student understand the basic principles? If so, will he be able to see their implications beyond science? There seems to be a hint here of indispensable topics, the basic principles, making too weighty a list. A thorough study of basic principles might concentrate attention on subject matter to the exclusion of teaching of method and ideas. Many of us doubt if we can—or even should—teach *the* basic principles and their implications. A choice of a few basic principles might be wiser, giving time for other matters. The particular choice may not be very important, provided this restricted choice leaves time to study the development and inter-relations of the chosen topics.

### *Show what science is like, what scientific procedure is like, and what scientists are like*

These, I think, are the most real and probably the most important things we expect from a science course. Our courses should mediate between the scientist and the layman, between a classical culture and a scientific civilization. They cannot do this just by pouring in scientific information or even formal training. What is needed is a sympathetic understanding of science and the way scientific work is done. To make this understanding a lasting part of peoples' culture is a huge task. In a year's course we can give only glimpses of it.

If the student is to retain such valuable knowledge and ideas, we must give him opportunity and time to make them his own, not just have them thrown at him by a provident teacher. Some students will need to learn what scientific work is like by *doing*, by experimenting independently in the laboratory, and thinking about the meaning of their experiments. Others need not be restricted to this excellent but very slow way of learning; they can learn by studying the work of the

great men of science, watching its growth in the framework of science against the background of history. Others can learn from direct teaching of science—science as it now is, with considerable attention to the way it has grown to its present state. Class groups with many students probably need a mixture of these approaches.

Whatever examples of scientific work are chosen, they should be studied thoroughly so that students can see the way the work was done and appreciate the methods used, so that they do not merely learn the results (for examinations) but see how those results take their place in the framework we call science. In particular, they should see how theory and experiment are related in each example studied. They should see how both the work and the results are related to the social and intellectual life of the times when the work was done, and perhaps see how they affected the life of later generations. Such general understanding of science needs specific examples but these cannot just be presented as glimpses. The student must understand the facts well, then think about their meaning and relationships. The teacher must help him to turn his attention in different directions, and must encourage him to generalize the understanding he is gaining.

To understand *what science is like* is a big requirement. We have only to look at the popular misconceptions of science—in a civilized world where science has been taught to many for generations—to realize that these cannot be due to unsuitable teaching alone. To show *what scientific work is like* is easier, because separate examples can build such an understanding and the student can see more easily what kind of thing he is learning. Perhaps easiest of all is to show *what scientists are like*; not in their personal characters,<sup>2</sup> but as thinkers and workers. Students should see how some of the great scientists approached problems, how they worked, and what their results meant to them and other scientists. They can learn the ruthless truthfulness with which scientists try to base their work on experiment. They can see experiment and theory playing their complementary roles in the hands of real scientists. They

<sup>2</sup>Some teachers suggest that the actual lives and characters of great men of science form an inspiring example for students, but many of us disagree. I would dread to see a government scientific project run by Tycho Brahe, Galileo, and Hooke. Personal details are imported by professional historians (under a claim of accuracy). I feel such details are unwanted here except where they make the nature of the scientist's work clearer.

can learn how theories (or conceptual schemes, or even just "ideas") are neither wild guesses nor true pictures, but wise imaginative complexes of ideas and knowledge which coordinate thinking and promote further knowledge. If students can learn such things as these, they will form a new generation of laymen able to appreciate scientists and work with scientist neighbors with delight and understanding.

Looking back over this list of overlapping aims and hopes, we see we shall want to construct our courses in ways likely to promote transfer. I shall not carry this discussion of aims further. Each of us should make his own list and decide his own order of importance. In spite of differences most of us will agree that our aims for science courses in general education go far beyond fact-content or even general scientific principles and include much more general understandings.

#### QUANTITY AND ARRANGEMENT OF SUBJECT MATTER

Our discussion of aims suggests that while details of content are not very important, the *quantity* of content and the general structure of topics are matters of great importance in the new courses. Accomplishment of most of the aims requires time. There must be time for student discussion, for careful reading, for historical analysis, for arguments and expositions of the nature of science; above all, for the student to turn around often and look back on the way he has travelled, trying to understand what it is all about instead of merely knowing facts or rules soon to be forgotten. Some teachers claim that the history and nature of science *are* discussed in orthodox formal courses. But it seems certain that orthodox courses do not give sufficient time for this, and, by their very crowding and attention to preparation for later courses, give an erroneous picture of science. Thus a general characteristic of the new science courses seems likely to be a great reduction of subject matter. To make discussion easier, I offer the following descriptions and labels. See Figure 1.

Let us represent the whole field of scientific knowledge by a tall wide stripe, ABCDD'C'B'A', in which a narrower stripe such as BCCD' represents a single science, for example, physics. (I shall use physics as my example, but another science would do equally well.) The orthodox course proceeds straight down a narrow stripe, covering the subject matter as thoroughly as time

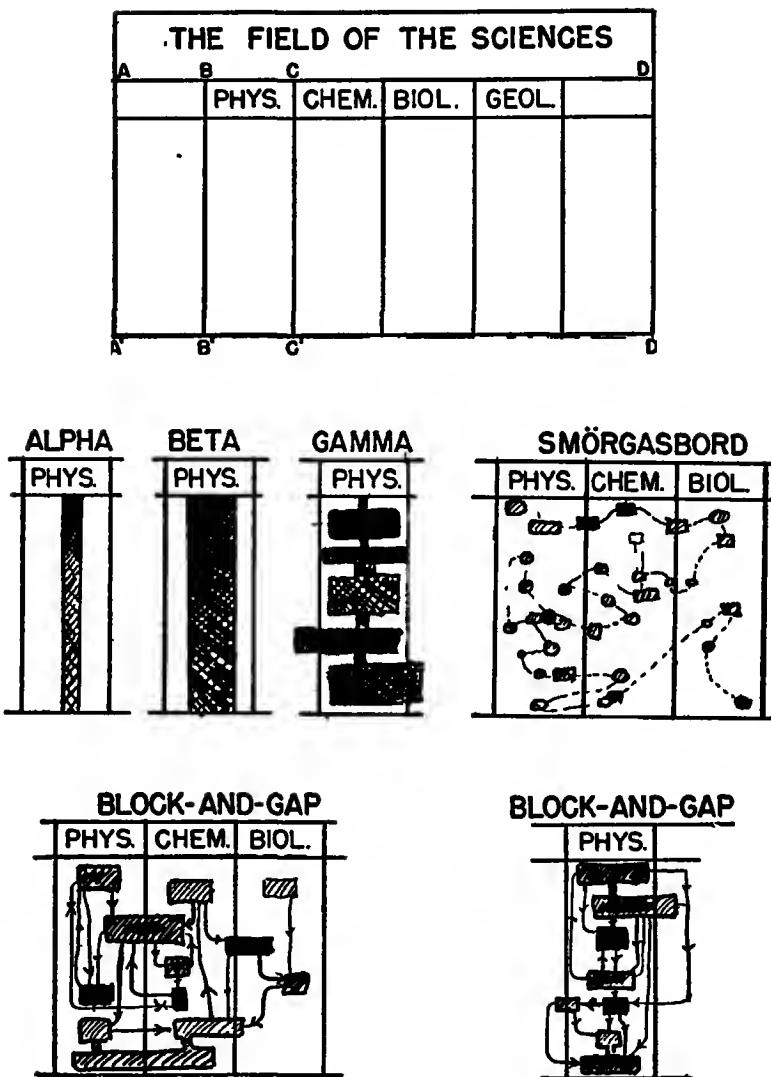


Figure 1. Quantity and Arrangement of Subject Matter

and the students' preparation will permit, usually trying to lay a foundation for later courses. Some colleges have several such courses for students with different preparation or interests. These are sketched as alpha, a "thin" or easy course which begins at the beginning and mentions topics thoroughly but

avoids the hard parts of the treatment. In physics, such courses are often recommended for students who have not studied physics before, and they are sought by many premedical students. They seem hard enough to their clients, but to their instructors they often seem too easy and too dull. In tests, easy numerical problems are more common than derivations involving argument, and the student's real understanding is not inquired into.

Beta is a standard "freshman course." All the important topics are treated in turn, often with little time to show their consequences or their interrelations. History is mentioned but not discussed and certainly not brought to life. The course is well packed with content. In physics courses of this kind, problem-solving still involves many arithmetical substitutions but contains some algebraic argument.

Gamma is a harder or more advanced course given in some colleges, for students with special preparation or interests. Note that since such courses trade on students' previous preparation, they can omit considerable patches of material, while expanding others and even treating them as case histories. Curiously enough, a gamma course is often a specially hard version of the block course suggested for general education. I think there is a useful moral in this for the future development of all courses.

One type of new course for general education has been a "survey" course which at least mentions a large number of topics. Some claim that this gives valuable wide acquaintance; others condemn it as giving a smattering of facts with no time for either thorough treatment or discussion of ideas. We may sketch this by selecting some small patches all over the wide strip of the sciences. If we like, we may draw a connecting thread linking the many topics in a pattern, but little blood is likely to flow along so thin an artery. I call this the "smörgasbord" course. (The title "survey course" has several meanings and is best avoided.) As thus described—a wild rush through a host of little topics—this is not the course any of us wish to claim as our own, not even the proponents of several kinds of "survey." We each disclaim it, and perhaps think it is the course the other fellow gives! We feel the smörgasbord course does too little to show the structure and methods of science. Another of its dangers is that it tends to glorify the

"wonders of science," paint the romance in glowing colors, and make the scientist seem a wizard who dispenses knowledge and "explanations." Science courses should debunk such false claims.

A scheme better able to meet some of the requirements discussed runs more like the one marked "block-and-gap." This may be in a single science or in a mixture. Its essential characteristic is that large quantities of material are omitted outright, so that only some of the topics of an orthodox course such as beta are dealt with—say, half the topics. Those included are treated thoroughly as to subject matter (the blocks representing such topics are dense) and as to their background (the blocks extend out toward other topics and other sciences and are clearly related to other blocks). Connecting these blocks are lines along which flows the "lifeblood" of the course:<sup>8</sup> discussions and investigations, historical studies, ideas and information carried from one block to another, and thence enriched, to still another or back to the first one—showing the organic structure of science. The gaps are essential; they give room for the lifeblood to show interrelationships, and they reduce the content of the course so that there is time for discussion, time for ideas to sink in, and time for the student to look back and reconsider. Whatever our differences of aim and course structure, this name "block-and-gap" with its crude picture seems useful as a description of the kind of course we are trying to provide for general education.

Though they indicate something about the course structure, these pictures say little about the type of approach or treatment of the material which is selected, nor does the block-and-gap picture say what material is selected. In block-and-gap, the approach may be historical (as it may be in beta), perhaps through case-history studies or through readings of original texts, or it may be empirical by experiment; or the course may be composed of selections from an orthodox course, with a change of attitude. We are likely to agree on some general characteristics for the block-and-gap course: restriction of topics, attention to their interrelations, and prominence to student discussion and creative and critical work.

<sup>8</sup>Physiologists would rightly condemn the gruesome errors in this picture. It is given as a poor metaphor and not as an analogy.

Critics, seeing the sketches or the name "block-and-gap" for the first time, may complain that a set of unrelated topics lightly treated would make a poor course, a sort of emaciated survey. This is not the intention of the scheme. The blocks are meant to be related, by pointing the moral from one to the other by referring back to earlier ones or prophesying forward to future ones, and their topics are meant to be treated seriously. In fact, the blocks should be both dense and extensive. The discussions should be thorough, explaining essential points thoroughly, and they should extend to neighboring material, pursuing some of it to an advanced stage. For example: an orthodox course beta in physics will certainly treat the kinetic theory of gases, probably stopping at a prediction of Boyle's law and a brief mention of diffusion. In a block-and-gap course, kinetic theory may be selected as a block or it may be omitted; but, if it is selected, it is likely to be treated more slowly and thoroughly so that students have time to discuss its assumptions and to understand its mathematics (instead of learning the latter parrot-fashion for examinations), and to see its use as a theory. It is also likely to be treated more fully. If it is done at all, it is done well. Just saying, "There is a prediction of Boyle's law . . . Avogadro . . . diffusion . . .," then hurrying on to a new topic, may teach something about kinetic theory but it is likely to leave the student little the better in his understanding of science in general. He needs to have time to discuss the parts played by assumptions and the mathematical machine. And he needs to see more of the results that the theory can yield.<sup>4</sup> If kinetic theory is studied in a block-and-gap course, it may well be continued through comments on molecular speeds, velocity of sound, and a discussion of gas viscosity—with an experimental test of the theory's surprising prediction that gas friction should be independent of the pressure. Here is theory being used and tested, then used to predict the breakdown of its own prediction.

### THE BLOCK-AND-GAP COURSES

In giving block-and-gap courses we are offering as part of general education, courses in which we are trying to show,

<sup>4</sup>This is one of the more serious crimes of the orthodox courses, building up some theoretical treatment or general principles, and then not using them. Thermodynamics, in almost any general physics text, gives an excellent example of this crime.

by means of picked specimens carefully treated, what science is like, how scientific work is done, and what scientists are like as thinkers and workers. In preparing such a course the first thing we have to do is to make it clear to all who teach in it that the gaps are big, that they are not expected to cover all the ground of a course like beta. We should go further and assure them that there is no golden rule for choosing the blocks. "This is *your class*," I would like to say to my colleague. "Make your own choice of topics and do not try to copy mine. Be careful not to choose too many,"<sup>5</sup> and to make a selection which will show interconnections, making some kind of a framework of science. Then you and your class can go ahead and think and argue and discuss and learn about science. At the same time, the class will learn some scientific material. Though you choose only a few topics, and though much of your attention and theirs is concentrated on methods and ideas, they will learn some facts and learn them well enough to seem well educated in science in the old-fashioned sense. And they will be happy to continue reading and learning for the rest of their lives."

If we have reached some agreement about aims and decided on a block-and-gap course, we still have choices both of content and of manner of treatment or approach. These choices affect each other.

#### *Choice of topics ("blocks")*

Many of us feel that the choice of topics for content is a matter of secondary importance. These are the blocks, chosen from one science or several, to form a scheme of subject matter with some interconnections. In this choice of content, there are no *indispensable* topics, but when we are making our own choice it is helpful to study the choices made by others. So I hope that all who construct block-and-gap courses will publish lists of topics with some details of treatment and comments on their success.<sup>6</sup> In studying such lists we should be

<sup>5</sup>I would like to make a rule, saying "You are welcome to add topics of your own to the selection I am using, but for every one topic you add, you must delete at least one of my topics." When a teacher understands this rule, he often says, "In that case I do not mind so much about adding topics—I see it is the treatment of them that matters."

<sup>6</sup>When I discuss lists with colleagues I find no single topic labeled "absolutely essential," not even the conservation of energy; but some aspects of scientific method—for example, the use of hypotheses—are common to all. However, some topics seem to be favorites. Several physical science block-and-gap courses include among their blocks: Kepler's laws, Joule's work, atomic theory.

careful not to make our lists too big by trying to add everyone else's suggestions to ours!

### *Single science vs. several sciences*

The choice between several sciences and a single one is not so severe as it sounds. Comparing two actual single-science courses, one in chemistry and the other in physics, I find at least 30 percent of the topics are common to both. And the physics course extends into astronomy as well as chemistry till it is hardly distinguishable from a "physical science" mixed-science block-and-gap course. Our choice of topics may be influenced by the books available. If we avoid texts designed for beta, suitable textbooks are hard to find and many original writings are not available.<sup>7</sup>

### *Treatment of topics*

The choice of approach or treatment is the really interesting one. In fact it is the central problem discussed in other papers in this volume. We should judge or try each method in terms of our various aims, realizing that there need not be just one ideal method—it is more a matter of "giving the job to a good man and letting him do it his own way." Here are some of the approaches suggested:

1. *Historical development.* We follow the history of some parts of science, showing the way in which knowledge was gathered and used and ideas developed. We emphasize the historical stages of growth rather than accuracy of historical detail. (The order in which physics was discovered is the easy order in which to teach it to young pupils, but a pretty dull order.)

2. *Historical background.* By showing the life and work of scientists in their historical background we can show what scientific work is like.

3. *Study of original material.* This constitutes as an exercise in reading and thinking, and also assists in achieving purposes (1) and (2). The great scientists wrote for others to understand, and where good translations are available their writings can be of great use.

<sup>7</sup>One could write a text for block-and-gap courses, but it would be bulky if it avoided smorgasbord attitude. Further, it should contain extra blocks which other courses may choose. This would make it very large, and would raise the danger of teachers trying to cover all the blocks in it, then we should be back at beta.

4. *Case histories.* This is a healthy combination of (1), (2) and (3), in which the blocks are large carefully chosen pieces of discovery, well documented by a mixture of original material and commentary.

5. *Orthodox presentation of some material, without historical background.* This method enables students to cover a block rapidly and it leaves considerable time for discussion. Used alone, this treatment might develop into beta; but mixed with the other treatments it can be a healthy accelerator.

In treatments using historical material teachers should give both students and themselves a feeling of the delight of investigation and discovery. They should avoid a worrying preoccupation with historical exactitude, which comes from genuine interest in professional historians, and from a sense of guilty inferiority in amateurs.

#### *Laboratory work*

Most of us feel that some laboratory work is essential. "Learning by doing" goes much deeper than "learning by listening," and for some students actual laboratory experimenting is the only way of giving an understanding of scientific work. It gives them a feeling of familiarity and respect for the foundations of science. Without it, texts, original writings, and even teachers take on an air of sacred authority. Some professional scientists argue against laboratories in such courses; looking back, they object that their elementary laboratories were boring and worthless. They forget they were unusual students; or they are rightly blaming a formal laboratory course. Dreary routine experiments with cookbook instructions can hardly give a sense of discovery or inspire a love of careful experiment or even give a respect for science.<sup>8</sup> Bored instructors who say, "Do that again till you get the right answer," make laboratory work do more harm than good.

But laboratories need not be like that. They need experiments which have some flavor of genuine investigation, not ones which just give training in techniques or servile "verification" of known laws. Tests of laws can be good indeed, but

<sup>8</sup>Even the reports required in most beta laboratories are deadening. They insist on childish records of the obvious, such as lists of apparatus used and statements like this, "I took a thermometer . . ." They urge students to use the clumsy English of the professionals, saying, "A thermometer was taken . . ." I hope we can avoid the latter in our new courses.

need a different attitude. The student needs time to try his experiments his own way, repeating them if he wishes. Then students and teacher need time for discussion, to see what can be drawn from the experiment and why. Most experiments should be simple and should be allowed to run for two or more weeks; examples might be a simple chemical investigation, an empirical study of spring-stretching, or a simple dissection. With fewer experiments than beta, the equipment need not be expensive, but the staffing raises serious problems because the instructors need to be keen, patient, sympathetic well-informed scientists who have the aims of the course at heart.<sup>2</sup> We need informed enthusiasts.

### STUDENTS AND THE NEW COURSES

Suppose, then, we have arranged our course and gathered our staff. Students on arriving make two complaints. The first one, "This course is different from our school science," shows how seriously new courses are needed in college and in high school.

#### *High school science*

Many schools give a children's smörgasbord course which makes science seem just a pile of wonderful fact-knowledge in which names have a strange ability to explain things. Such courses stimulate interest, increase knowledge, and decrease superstition, but they damage the student's picture of science. With more thought about aims, less material, more careful discussion by teachers who are competent scientists, these courses could become excellent parts of general education. In other school courses, a dry skeleton form of alpha is given, with rules and names stated authoritatively and definitions printed in heavy type. Students emerge from these with little feeling for the experimental basis of science and little idea of scientific

<sup>2</sup>Some colleges feel laboratories would be too costly. If student numbers are increased, there are serious problems of staffing and housing, but although sympathetic staffs are essential they need not be numerous. Relieved from pressure to "get the right answer" in a hurry, students are not lazy, but take more care and like wrestling with their problems without much help. Restriction to very simple equipment is almost an advantage. As an example: a student's wristwatch used with a cheap magnifying glass is better than a real stopwatch. The planets in the sky provide a free laboratory. It is interesting to find the new courses using that vast frictionless laboratory in which Galileo and Newton tested their mechanics. I suggest we might draw upon those masters for other suggestions for laboratory work. Devising good experiments is hard. A symposium on laboratory experiments would be of great use.

method or attitude. "In school," a student states, "we were taught to put the numbers in formulas and get the right answer."

We could change such school courses into better ones if we could encourage school authorities to think out the aims of science courses just as we are doing for college courses, and if we could equip teachers with both the knowledge of science and the understanding which we hope they will give. This raises problems of training teachers. For our purpose, the usual training courses may do harm. College block-and-gap courses are needed, and in addition some formal courses in subject matter so that the teacher has a sound background. In a few generations we hope to find new science courses in colleges and schools feeding each other with teachers and students. But, more immediately, much could be done by conferences with teachers, in which aims and methods are discussed. Such conferences could encourage many to embark on new courses.

#### *Future science specialists*

Another complaint made by students is: "This will delay us if we plan to make science our major field." This raises a real difficulty and I think the answers to it are:

1. "There will be some delay in your professional preparation, but we think your gain in understanding science will compensate for that. Such understanding is as important for you as for any."

2. The material you *do* learn in this course will be learned so thoroughly that you will remember almost as much some time later as you would after an ordinary (*beta*) course."

3. "You will know so much about the ways of science that you will find it easy to catch up very quickly. A single semester supplementary course will carry you beyond the end of an ordinary course." I suggest that

$$(\text{block-and-gap}) + (\frac{1}{2} \text{ year supplement}) = \text{more than beta, or} = \text{gamma}$$

This problem is especially serious for premedicals. However, if they take their science courses, as many do, in a bored or unwilling frame of mind, they are better in beta or alpha. The block-and-gap course needs willing customers.

#### *Student contribution*

As the course runs, students bring many contributions to its tempo and structure, and the receptive teacher uses these. Such

flexible adjustment between course and students is vital help toward transfer.

With time to discuss and understand, with opportunities to learn by doing, many a neutral student becomes an enthusiastic participant. The insistence on real understanding brings a sense of success, and nothing succeeds like success. I do not mean that all the students in the course will learn to love its methods or material, but I do hope to find great general interest, and a willingness to study hard at something that seems genuine. We need to feel the pulse of the course in discussions with students. Some actual teaching can, in fact, be done by discussing the course itself and its aims. We can promote transfer by explaining its possibility.

### *Examinations and assignments*

In setting examinations and in assigning problems, we set the tone of the course, in the minds of both teachers and students. So we must make our questions consistent with the course and its aims. This seems trite; but it is very hard to construct such questions and very easy to slip back to the fact, number, and name questions so common in beta or alpha.<sup>10</sup> We can make questions which do test the real work of the new courses and it is surprising how successful they can be. Good students find great opportunities in them. Students who do poorly show quite clearly that they have not been awake in class or present in the laboratory; and we have no feeling that we are just grading English compositions. As samples I suggest: "What constitutes a successful experiment?" "Are the results of physics really true?"; essays describing great pieces of scientific work; or, with longer time, the writing of a critique of an article, an experiment, or even a book. If we lose some accuracy in grading, is that too disastrous, if we maintain the spirit of the course?

### TEACHERS

In our discussions, one thought recurs, embarrassing but insistent: Who will teach these courses? The courses need keen teachers who will enjoy working toward new aims and will join in seminars to discuss aims and attitudes, who will refrain

<sup>10</sup>Examples: "What is the action of hot sulfuric acid on copper?" "A gas occupies . . . . Calculate its volume at . . . ." "What is the difference between cohesion and adhesion?"

from lecturing and laying down the law and will give quiet guidance and encouragement instead. They must have a solid background of scientific knowledge so that they can discuss with wisdom. They must even feel so confident that they will keep silent while students think; and, when necessary, will answer with an unashamed, "I do not know."

The teacher's role in the new courses reminds me of the epilogue to Drinkwater's "Abraham Lincoln":

But, as we spoke, presiding everywhere  
Upon event was one man's character,  
And that endures; it is the token sent  
Always to man for man's own government.

Wise teachers with selected material and wide aims well in mind can make new science courses play a great part in general education.

## A General Course in Physical Science at Haverford College

ONE OF the consequences of a re-examination of the program of Haverford College is the inauguration this year of a few general courses. The reasons for trying them at Haverford are probably not notably different from the reasons behind similar moves at other institutions. We considered carefully the ideas advanced in the Harvard Report<sup>1</sup> and the account of Columbia's program outlined in *A College Program in Action*.<sup>2</sup> Discussions with representatives of a number of other institutions, including Colgate, Chicago, Amherst, and Wesleyan, have also been helpful in formulating our general ideas. Our plans for a general course in physical science were influenced by valuable discussions with men who have taught a somewhat similar course at Bard College.

Obviously, we are not alone in feeling that the educational system is far from perfect. If education is to claim any credit for the advances made by society, it must at least share the blame when things go wrong. With something like this in mind, many college people concluded that change was necessary, and one of the changes proposed was a reduction in specialism, with increased emphasis on general education.

Since the term "general education" is used with various meanings, it would perhaps be well to make a few comments on the sense in which it is used here. Many people use it as a synonym for liberal education; I prefer not to use it that way, but to divide liberal education into two parts, general education and specialized education. Admittedly, much of specialized education is far from liberal, but I do not think that it is necessarily so. I believe that some specialized education is an im-

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<sup>1</sup>*General Education in a Free Society* (Cambridge: Harvard University Press, 1945).

<sup>2</sup>*A College Program in Action* (New York: Columbia University Press, 1946).

portant part of a liberal education. From this point of view, general education is that part of liberal education which is not specialized, which does not have as its principal goal the mastery of some particular field of knowledge.

Before the war, Haverford operated under a system quite similar to that in use at many other colleges, under which each student was required to take a course or courses in each of several fields. The science requirement could be met by a course in chemistry, for example; the social science requirement by a course in economics or history, and so on. Although this system gives some breadth of distribution, the particular courses taken to secure this breadth are often too narrow in their point of view. Many, if not most, of such courses are first courses in a department, designed primarily as the beginning of specialization in that department. Many of us now feel that it is unreasonable to expect a given course to serve simultaneously as general education for some students and as the start of specialized education for others.

#### GENERAL COURSES IN SCIENCE

With these ideas in mind, we have set up three general courses, in humanities, biological science, and physical science, and have laid plans for a fourth, in social science. In addition, one section of freshman mathematics is being taught in such a way that it might be considered a general course. These courses are among the electives which may be chosen to meet the distribution requirements.

For the present, no one of these courses is required of all students. We are of the opinion that required courses, in general, are not regarded kindly by students, and hence are less likely to be successful than are electives; the only strictly required course in our curriculum is Freshman English. It is hoped that eventually it will be possible to set up the program in such a way that, if the general courses in social sciences and humanities are successful, almost all students will take them. It is not intended at present, however, that the general courses in the natural sciences will come even that close to being required.

The science requirement in the new program is two years of science, chosen from two of the three groups: physics-chemistry, biology-psychology, and mathematics-astronomy. In the physics-chemistry group one of the courses is the gen-

eral course, which, as is described in more detail later, also includes material from astronomy. Other courses in this group are general physics, a rather stiff course, and second-year chemistry, which may be taken by students who have had a good course in chemistry in high school.

If the distribution of students among the three groups were uniform, two-thirds of all students would take a course in the physics-chemistry group. Of these, very few would take the general physics course alone, although a good many would take it after the physical science course or after second-year chemistry. Quite a number take the second-year chemistry course. Of course, some students take courses from all three groups; premedical students, for example. Our best estimate is that a little less than half of the students in college will take the physical science course, if the course proves successful. If its success should even exceed our hopes, it might be desirable to change the pattern by one device or another so that most or all students would take it, but there is no serious thought of this at present.

We find ourselves in substantial agreement with many of the published views of two men who have given much thought to the place of science in general education, President Conant of Harvard and Dean French of Colgate. Speaking at Princeton late in 1944, President Conant said:

The present college courses in physics, chemistry, and biology by necessity are arranged primarily as a foundation for more advanced work. Therefore they do not fulfill the function of providing for the nonscientific student an adequate introduction to the methods by which knowledge has been advanced in modern times. Such courses fail to meet the educational requirements for the nonscientific student both because they require too much detail as a basis for subsequent scientific courses, and also for another reason closely related to the complexities of our modern industrial society. Those who give such courses, and I am referring in particular to physics and chemistry, feel that they must cover those branches of the sciences which are concerned with everyday applications and also must refer to the most recent discoveries. As a result a rather superficial treatment of many phases of physics and chemistry cannot be avoided.<sup>3</sup>

Dean French recently put it this way:

What is the function of the basic science course? Is it to lay the foundation for further technical work in the field, or is it to provide some under-

<sup>3</sup>James B. Conant, "Science Courses for Non-Scientists," *Proceedings of the Conference on the Natural Sciences in the Liberal Arts College*, held at Princeton, N. J., December 1-3, 1944; published March 1945 by Princeton University.

*standing of science?* If it is the one it can no longer do a respectable job on the other, in spite of reassuring statements to the contrary appearing in many college catalogues.<sup>4</sup>

Reasoning in similar vein, we have attempted to develop a course with the stated aim of giving a broad understanding of some of the principles upon which all physical science is built. Coverage of the field, development of technical skills, glorification of the role of science in modern life, and preparation for later courses have no place in the course which we have tried to develop. The subject matter has been chosen for its value in giving an understanding of science, and in illustrating the methods of science, the methods by which knowledge of the physical world is obtained.

An obvious criticism is our failure to include material from the biological sciences; the equally obvious answer is that there is in the field of physical science plenty of material which will help give an understanding of science, and since coverage is not an objective, there is no compelling reason to include the biological sciences. In addition, there is the real difficulty of finding someone on our campus or available elsewhere who is competent to teach a course including all the sciences. A critic might then say: Why not limit the field to one science, such as physics or chemistry? We might do so, but we would run the risk of having the course, let us say in chemistry, be just another beginning course in chemistry; we would then be right back where we started, with the points raised by President Conant and Dean French untouched. In addition, there is more unity between physics and chemistry than there is between the physical and biological sciences, and as will become apparent later, we have no objection to coherence if that can be achieved without sacrificing other things. We decided to start with separate courses in biological science and physical science; what follows is a report on the course in physical science.

#### THE COURSE IN PHYSICAL SCIENCE

The course is designed for any student who wishes to elect it, other than those who have already had college work in chemistry or physics. Whether or not the student intends to con-

<sup>4</sup>S. J. French, "The Need for a New Approach to Science Teaching," *The Wiley Bulletin*, New York, December 1947.

tinue with science is immaterial. This year, the first year in which the course is given, there are a number of upperclassmen in the course — adventurous souls who are interested in trying something new, and some who have postponed fulfilling the science requirement until now. Ultimately, we will have mostly freshmen, a few sophomores, and only occasional upperclassmen. There is no prerequisite to the course; we assume no chemistry, no physics, and only such mathematics as is the usual minimum for admission to college.

#### *Development of the course*

Before the course was started there was some discussion of limiting it to students who did not intend to continue with science. The view which prevailed is that the course should not be so restricted. There are a number of arguments for this view. A minor point is that students at Haverford do not select a major until the close of the sophomore year, and we are not prepared to shift the decision as to principal field of study to the beginning of the freshman year. A second point, brought out rather convincingly in conversation by Professor Beckman of Columbia, is that the presence of "serious students" in a science course tends to raise the general level of the course. We do not want the course to arouse the emotions in our students which caused a chemistry course for nonscience students in one of our best institutions to be called "housemaid's chemistry." Third, and most important in my view, is that the course, if successful, will be just as valuable to students who will later specialize in science as to those for whom it is a full half of their total experience in science.

Much of the thought which has gone into revision of science courses has been concerned with science for the nonscientist. Apparently President Conant, both in the address already mentioned and in his more recent book, *On Understanding Science*<sup>8</sup>, is concerned with science for the nonscientist. Dean French's paper also speaks of "science courses for nonscientists," which implies, perhaps unintentionally, that some other course is preferable as a foundation for further work in science. We raise the question: Should not the scientist be given the same opportunity to understand science that the other student has? Tacitly, we are inclined to assume that the science student

<sup>8</sup>James B. Conant, *On Understanding Science* (New Haven: Yale University Press, 1947).

will come to understand science during his study of it—an apparently reasonable assumption, but not necessarily true. I believe, and some but not all of my colleagues agree with me, that this assumption is too often not true and that the science student can profit greatly by starting his college work in science with a course aimed at giving an understanding of method and the philosophy behind the method.

The danger, of course, in admitting students who intend to continue studying science is that there will be a tendency to include material in the course for the sole reason that it will be "helpful" to them in later courses. We intend to keep alert to that danger, and we feel that for us the danger is not very great. Our course is manned by a physicist, an astronomer, and a chemist, and it is not altogether facetiously that I point out that any one of us can be outvoted if he proposes introducing subject matter whose only merit is that its inclusion would simplify the work of his department.

Another difficulty is in a sense the converse of that just mentioned: the objection which teachers of later courses in the individual departments justifiably raise when some of their most interesting subject matter is stolen by the general course. This is a much more serious difficulty, which would not arise if no students in the general course went on to more advanced work in these departments. It could be solved in a cold-blooded way, if all students went through the general course, by telling the teachers of the other courses that in the best interests of the college they would have to give up that particular subject matter. (I suppose that the dean would have the job of telling them.) But since not all students in the advanced courses will have taken the general course, that solution is not only distasteful but would be no solution.

However, the difficulty is not insurmountable. The point of view in the general physical science course is so different from that in the departmental courses that what appears to be duplication is often not actually duplication. This is particularly so where material from physics is concerned. In chemistry, we intend to offer a new second-year chemistry course for those who take the general course and then want to go on in chemistry, given by the chemist who teaches in the general course, and so designed that those who take it after the general course will be ready to join those who have had high

school chemistry and the regular second-year chemistry course. Any material beyond that level which seems to be duplicated in the general course would be presented so differently that no problem would arise.

At the time of writing, the first semester is completed; consequently comments on the program for the first semester are based on experience of a single trial. The program for the second semester has been laid out in detail, but it is as yet untested. Our guesses as to time required were surprisingly accurate for the first semester; there is some reason to anticipate that we may not be very far wrong in our time estimates for the second.

The course meets three hours each week for lectures, and is divided into sections of about twenty students each for discussion and laboratory work, each section meeting once a week for two and a half hours. There were fifty-one students enrolled in the course during the first semester; about five of these, for one reason or another, are not returning for the second semester.

### *Content of the first semester*

At the beginning of the course, we handed to each student a rather detailed outline of the course as planned. An idea of the work of the first semester can be obtained from the abridged version of the outline which follows:

- Remarks on the scientific method
- Velocity in one direction
- Acceleration
- Scalars and vectors
- Vector velocity and acceleration
- Constant acceleration
- Projectile motion
- Momentum
  - Conservation of momentum
  - Conservation of mass
- The scientific method
- Force
- Ptolemaic and Copernican systems
- Law of gravitation
- Special relativity
- Work
- Heat
  - Definition of temperature and temperature scales
  - Friction

Mechanical equivalent of heat  
First law of thermodynamics  
States of matter  
Vaporization and fusion: latent heats  
Deductions from first law  
Gas laws  
Kinetic theory  
Heat as molecular motion  
Deviations from gas laws  
Modifications in kinetic theory  
Combustion  
Other combination reactions  
Decomposition reactions  
Pure substances  
Displacement reactions  
Atoms  
Molecules  
Properties of oxygen and hydrogen  
The nature of chemical change  
Properties of some other elements  
Laws of chemical composition  
The atomic theory  
Atomic and molecular weights  
Fundamental theory: logical development of atomic and molecular weights,  
formulas, equations  
Classification of elements  
Periodic law  
Thermochemistry  
Reaction velocity  
Reversible reactions  
Equilibrium  
Second law of thermodynamics  
Further analysis of the scientific method

We started the course with a very few remarks on the scientific method, delaying more detailed discussion of this centrally important subject for about two weeks, feeling that a little background would make the discussion more meaningful.

The first few topics need no comment. When we came to momentum, we developed the concept of mass by the method of Ernst Mach. This is quite a departure from the conventional method of presenting the concept of mass in elementary physics; we took this departure deliberately and we feel that it was reasonably effective. As with much of what we have done, we are confident that this method of presentation can be still more effective another time. One reason for presenting mass in this manner lies in the fact that there

are in the course students with varying backgrounds; some have had physics in high school and some have not. The development of mass in the conventional manner might seem like a familiar story to the former group. It was our hope, and on the basis of our limited experience a fairly sound one, that we could present the concept of mass in a manner just as convincing as the conventional presentation, more logical, and no more difficult for those who have not studied physics, and by so doing avoid the feeling among those who have already studied the subject that this course is just repetition of high school work.

It was at this point that we introduced a detailed lecture on scientific method. We feel that our decision not to do this at the very start was a wise one, but that probably two hours or more should be devoted to it rather than the one which we allowed.

The Ptolemaic and Copernican systems were presented as logical explanations of observed phenomena; we discussed the relative merits of each, using this discussion to illustrate the fact that two theories may, at least for a time, both be consistent with the observed facts. The study of gravitation included application to the solar system and to the earth's and sun's attraction for the moon.

The introduction of special relativity may cause some surprise. The point of view taken was that Newtonian mechanics seems quite satisfactory, but when examined sufficiently closely, with attention to details (for example, the Michelson-Morley experiment), it fails to fit all the facts. Although it is doubtful if any members of the class are now experts in relativity as a result of this brief exposure, we feel that the inclusion of this material is worthwhile as illustrating very effectively the danger of assuming as true even that which is so obviously "true" as Newtonian mechanics. Another time, we expect to devote more, not less, time to this subject.

The logic of the next few topics is probably sufficiently clear so that detailed reasons for presenting them here are unnecessary. However, I should like to comment on our introduction of the first law of thermodynamics. We used this term deliberately, rather than the less frightening one of "conservation of energy." We wanted right here to start the class

thinking in the broadest terms at the same time that they used very specific examples. We pointed out how this law was established, by inductive reasoning from many observed facts, and how deductions could be made from the law; for example, we deduced from our discussion of states of matter and from the first law that the energy change is independent of the path. It seems to us that this is a particularly clear example of deductive reasoning, and we labeled it explicitly as such. Throughout the course, when we have occasion to discuss laws, we take the opportunity to show how the evidence is gathered and checked and how the statements of what we call laws are generalizations of individual bits of related evidence.

Among the best examples of inductively established scientific laws are the gas laws. Together with the statement of the laws and discussion of the evidence on which they were based, we gave a qualitative description of the behavior of gases. The kinetic theory was then presented as a logical explanation of all these facts, and deductions from the theory were also discussed. Deviations from the gas laws, and the very existence of liquids and solids, were presented to show the necessity of modification in the original kinetic theory. It was pointed out that the very fact that modification was necessary, and was successful in explaining more detailed facts than the original theory could handle, was additional evidence for the validity of the theory in its main outlines. In the discussion, of course, we referred back to concepts developed earlier—to mechanics, in discussing the explanation of pressure, and to heat effects, in discussing liquids and solids. We made a special point of the use of "models" as a general technique in science, in this case "small hard spheres" as preliminary models of molecules, followed by the change in the picture necessitated by greater precision in measurements.

Having discussed motion and energy, particularly heat energy, and having introduced matter in connection with states of matter and the kinetic theory, the introduction of changes in matter seemed logical here. We agree with President Conant when he says that the development of ideas of combustion makes an excellent example with which to convey an understanding of how science grows. We agree with him in emphasizing the phlogiston theory, its successes and failures, and

in following the reasoning and experiments of Lavoisier in trying to make clear the nature of combustion. Hindsight indicates that we would have done better to have followed President Conant's treatment in even more detail than we did.

Before studying the beautifully systematic logic of the "fundamental theory" of chemistry, it was necessary to introduce a little more or less purely factual material. The descriptive chemistry was kept to a minimum—about four hours gave sufficient background for an understanding of the more general principles which followed. Our treatment of the development of the logic used in arriving at our present knowledge of atomic and molecular weights, formulas, and equations, is not particularly original. Professor Meldrum, of our chemistry department, has for years been presenting this material in a very systematic way, as have others. Original or not, the material is admirably suited to a course of this kind, and although the reasoning is not easy, it is straightforward and can be followed and understood by reasonably intelligent students at the freshman level.

In our discussion of the periodic law, we emphasized the nature of the evidence on which the law is based, and the relationship of the law to the chronological development of other parts of science. This is an excellent example, almost an ideal example, of a law which could not be enunciated until the way was cleared for it by the development of certain other concepts, and which, once the way was clear, was discovered practically simultaneously by different investigators. We discussed the chronology of the development of knowledge of atomic weights, and pointed out that soon after the atomic weights were established, the law was clearly stated by not one but two independent investigators, Meyer and Mendelejeef. To emphasize the point, we discussed the fumbling efforts at classification of the elements which were made before the unequivocal establishment of the table of atomic weights. We also mentioned Newlands' work, showing how his lack of scientific intuition prevented his contribution from being as valuable as that of Mendelejeef and Meyer. At the same time, we made clear that the way was paved by Newlands and others who failed to see the full significance of their work.

In the discussion of thermochemistry, chemical reactions and heat energy were shown to be interrelated. In connection with reaction velocity, the factors affecting reaction velocity were discussed, as well as the insight which such studies give to the mechanism of chemical reactions. Reaction velocity also served to introduce the concept of chemical equilibrium, which was used as the introduction to the second law of thermodynamics. This law was presented as applying not only to chemical systems approaching equilibrium, but to other processes, some of which we had already studied, such as equalization of temperature, the interdiffusion of gases, and the impossibility of obtaining work continuously from heat. Although the second law may seem a bit advanced for this course, the class seemed to encounter no particular difficulty with it, and a question on this subject on the midyear examination was handled adequately.

In the final lecture of the semester the methods used or implied to date were reviewed and the interrelationships of the various parts of science which we had discussed were pointed out. Another time, we could well spend two or three hours on this material.

Our feeling at present is that the semester's work was fairly satisfactory. As I have indicated, we should have put more time on some topics; unless we decide to omit some topics, we shall have to extend this part of the course over more than a semester, which will necessarily mean cutting down on what we have planned to do in the second semester. Detailed decisions of this sort concerning our plans for another year will have to wait until we have completed the second semester and can judge the course as a whole on the basis of the first year's trial.

#### *Content of the second semester*

In the second semester we intend to consider electricity and the electrical nature of matter, again with primary emphasis on the way in which the various concepts have developed. We shall start with electrostatics and magnetostatics, introducing here explicitly the important concept of field, which was only implicitly introduced in connection with gravitation. Then will follow electromagnetism, electrolysis, and Faraday's laws, with the hints drawn from the latter of the atomic nature of electricity.

This will be followed by electrochemistry: the properties, including the colligative properties, of solutions of electrolytes; the ionic theory and some of its consequences; electrodes, electrode potentials, and galvanic cells; and the interpretation of oxidation-reduction reactions and the electrochemical series based on the ionic theory.

Optics will be treated next, with particular emphasis on the wave-particle dilemma. Then we shall discuss the spectrum and the applications of spectroscopy to materials near at hand and in the stars, to the motion of the stars, and to photochemistry.

Atomic structure will be the next major topic, starting with electric discharge through gases and taking up Rutherford's scattering experiment, x-rays and atomic numbers, and early atomic models. Nuclear structure will include radioactivity, isotopes, and nuclear transformations, including fission. The arrangement of electrons and consequent interpretation of the periodic system will follow, as well as a discussion of electronic theory of valence and, if time permits, theories of solids, liquids, and gases.

Regardless of what else we have to omit, we intend to end the course with a backward and a forward look—a recapitulation of methods used, similar to that given at the close of the first semester, and a consideration of some unsolved problems and of some of the contributions of science to philosophy.

### *Laboratory*

Laboratory work is an integral part of the course. During the first semester we performed ten experiments, and each student spent one evening at the observatory. We have gone on the principle that we would do experiments if they furthered the main purpose of the course—increasing the student's understanding of science. When no suitable experiment occurred to us, we omitted laboratory work and devoted the time of the laboratory period to discussion, oral quizzing, and working of problems under supervision of, and with the help of, the instructor. These few discussion periods may not have been adequate; it would probably be better to do still less laboratory work and devote more time to discussions. Problems were assigned almost every week, and the more difficult ones were discussed at the beginning of the laboratory periods.

The development of laboratory techniques is not one of our objectives. Hence several of the experiments were done as class experiments, using a single apparatus and with the members of the class taking turns making observations and measurements. The first experiment was linear measurement, done individually. Each student measured the length of the room, and then measured length and diameter of some small cylinders. These measurements gave us an opportunity to discuss errors and to show how experimental data can be analyzed and their reliability evaluated. Other experiments were: acceleration due to gravity, the Cavendish experiment, and the heats of fusion of ice and condensation of steam, all done as class experiments; Boyle's law and Charles' law, done partly as class and partly as individual experiments; the law of chemical equivalence ( $Mg:H$ ), the gram molecular volume of oxygen, and the law of freezing point depression, done by students working in pairs; and the law of Dulong and Petit, done as a class experiment.

Each of the experiments chosen illustrates some important principle. In several cases, the point of view was that of "discovery" of the law or principle in question. In one case, freezing point depression, it was possible to bring the class to exactly the desired point in the lectures and continue from there in the laboratory. This is an excellent technique, and one which could be used more often. With large classes, of course, it is usually difficult and frequently impossible. At Bard College, where a somewhat similar course has been given for several years, the "discovery" experiment is used as a major feature of the course. They are able to do this because there are not very many students in any one course, and their time schedule is very flexible. We hope that we can develop our experiments in that direction more effectively in the future.

When the class went to the observatory, they were shown the motions of the heavenly bodies by means of a small planetarium, and then were taken outdoors and shown some of the easily recognized constellations, and were asked to make a rough chart of a section of the skies. When the weather becomes more dependable we shall use the observatory again, choosing times when observations of particular interest can be made through the telescope.

Student work of preparing laboratory reports is kept to a minimum. We feel that the students can profit more by reading in connection with the course than by preparing detailed laboratory reports. Most of the experiments are short enough so that the students can perform the calculations and make a brief write-up of the experiment during the laboratory period itself, turning in their final reports before leaving the laboratory. When they need help, they ask the instructor for it, and he is frequently able to see where they lack understanding of the principles involved.

### *Reading materials*

No single text is suitable for the kind of course which we are giving. We have purchased several copies of three or four books, which are on reserve in the college library, together with a smaller number of copies of several other books in which less extensive readings are assigned or suggested. The principal books used during the first semester are: Stewart, *Physics: A Textbook for Colleges*; Perkins, *College Physics Abridged*; Baker, *Astronomy: A Textbook for University and College Students*; and Meldrum and Gucker, *Introduction to Theoretical Chemistry*. At frequent intervals we hand out mimeographed sheets of required readings, optional readings, and problem assignments. Laboratory directions are also in mimeographed form. From time to time we give out other material which we think will be useful.

### *The staff*

This year three men are collaborating on the course: one is an astronomer, one a chemist, and one a physicist. Each man attends all lectures, but a laboratory section is handled by one man. This year, each of us gave the lectures on the material which he knows best, since in that way the task of presenting the course is lightened. This is not an ideal method, however, and in later years we hope to divide the work less along departmental lines. One objection to our procedure is that the students are inclined to label *this* material physics, because the physicist is teaching it, and *this* material chemistry, because the chemist is teaching it. We try to do away with departmental barriers in the students' minds, and the present system probably increases these barriers. Another objection

to this procedure is the danger of "specialism," the very thing which we are trying to eliminate in giving the course at all.

Admittedly, this is an ambitious program. It is not easy to teach this way; although we are all reasonably experienced in presenting the facts and theories, the point of view which we take in this course is new to us and involves careful preparation and still more careful presentation. Since coverage is not one of our objectives, elimination of some of the subject matter which is included this year will not disturb us greatly. We feel, though, that we have a program which is reasonably coherent; it will be a challenging problem to obtain more depth without losing too much of the coherence.

It is my hope that this account of our limited experience and our plans may be helpful to others who are thinking of changing their methods of teaching science. We are not convinced that our method is necessarily the best, nor on the other hand have we reason to think that we are on the wrong track. We intend to continue in our present direction for a while, hoping that a better understanding of science will be given in this way than is possible through the conventional departmental courses.

## **General Education in Natural Science at Colgate University**

**T**HE EXPERIMENTAL development of a program of general education at Colgate University, although not a new venture has, since the war, taken on such major evolutionary aspects as to constitute in fact something of a revolution. Working through the war, the Committee on the Postwar College critically analyzed the entire educational program of the college. Focusing first on the survey system, in operation for more than a decade prior to the war, and later, on other aspects of general and departmental education including the preceptorial studies program, the committee came to several conclusions which have motivated a sweeping revision of the prewar educational pattern. The wholehearted acceptance of these conclusions by the faculty and the willingness on their part to enter into a new experimental program, taken together with the prior experience of many of them in the cooperative survey system, has made the new way—at best difficult enough—a passable avenue for a considerable “road test.”

Although the committee was critical of the survey system which in prewar years consisted of five required one-semester survey courses covering the fields of physical science, biological science, social science, philosophy and religion, and the fine arts, it was by no means prepared to abandon the concept of general education. Instead, it reaffirmed its faith in such education, and at the same time planned for strengthening and extending the program. Accordingly, the five one-semester survey courses together with freshman English are being replaced by seven full-year courses in general education. These

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are designed to form the essential and sequential core of a college education, to which may be bonded those elements providing their own special properties of strength for each individual student.

The courses of this sequence, tapering in number from bottom to top, cover in the freshman year natural science, social science, and philosophy and religion; in the sophomore year, area studies, art, and literature; in the junior year, English communication; and in the senior year a correlative course linking the general education program to the student's special field of interest. These changes are coupled with others in the preceptorial studies program. This program which employs graduate as well as faculty preceptors, centers on the study of informal English and current problems for all freshmen. The elimination of freshman English, and the introduction of a proficiency test in foreign language, together with the foregoing changes, constitute the principal features of the Colgate Plan of Education now in its second year of operation. The new courses are being introduced at the several levels in successive years beginning with the freshman courses which started in September 1946.

The most significant changes, however, are those not easily reducible to paper. A mere lengthening or altering of course requirements or the substitution of general for special courses provides no lighted passageway to successful general education. The Committee on the Postwar College was aware of this in its insistence on a shift in attitude, approach, and method as well as content. It reported:

One of our most obvious concerns is to direct into college work the natural curiosity of the students who come to us, a curiosity that has often strayed or been driven from academic interests. One way to do this might be to give them the most information in the shortest possible time; a more fundamental way is to whet their curiosity by opening up fields through problems, some simple, some complex enough that the search for solutions challenges mature people and will challenge students on their way to maturity. Instead of dividing a field into its component parts and making an attempt to cover these, this approach would focus students' attention on a selection of concrete problems, and from these lead to the background, the generalizations, the theories involved . . . This method affects particularly the organization and methods of the courses. It means covering fewer topics but exploring them with more thoroughness.

President Truman's Commission on Higher Education also insists that the real difference between general education and special education is not so much in the materials of courses as in the attitude toward the content. The acquisition of a complete sequence of facts or principles is of far less importance in general education than the understanding of how certain facts or principles contribute to the solution of a problem. In natural science this concept leads away from a survey, necessarily superficial, of the highlights of modern achievement to a more careful study of a few problems, in an endeavor to understand what factors contributed to the solution—and how, and why. In the social sciences it leads to the consideration of "live" cases, what comes from them, why there is no one solution, what part emotion and bias play, and what can be done through objective analysis of the problem and scrutiny of the background. In philosophy and religion it leads to a consideration of a few great movements, their origin, why they mean one thing to a student in America and another to a student in, say, India.

In this sort of education, the student must be at the very center, an active participant at all times. Insofar as he is not, the method fails. The important thing is to provide techniques and arrange content in such a manner as to insure active student participation. Indeed, we must look upon content as essential only insofar as it is necessary to understand the particular problem. Nor can the problem, be it "live" or inanimate, become a mere example illustrating a principle. It must be an end in itself.

It is not easy for a teacher, with his normally strong sense of logical and chronological order, to adjust to this type of motivation. Nor is this method of teaching nearly as simple as that of lecturing on a specialty, where the student can, with a minimum of mental effort, fill a notebook and later regurgitate the contents in an examination. From serving as an authoritarian source of predigested material, the teacher must come to stand as moderator, guide, and listener. Indeed, the problem method if pursued in this spirit creates many problems of its own, not the least of which is the teacher's own adjustment to the method.

The present experiment at Colgate attempts to make use of as many teaching techniques as possible aimed to stimulate

the curiosity and through it the active participation of the student. At the same time it attempts to provide some brakes which the teacher may use to hold back his own enthusiasm and thus leave students to find their own answers collectively or singly. There is without doubt less "knowledge" passed across the board by this method, but if it leads the student toward greater effort to form judgments and conclusions and to analyze specific problems, even in the absence of all the facts and on a less than mature basis, we will feel repaid for the not inconsiderable effort involved. We have no illusions that we are following Alice through the looking-glass into that magic land, *Transfer of Training*. In fact, we are hopeful that the running we are doing may inch us ahead and even serve to show that training for better *understanding* in areas broad enough to overlap may at least minimize the need for transfer—and perchance even leave a residue of "knowledge."

It is against the background of this sort of approach to general education that the required freshman course Problems in Natural Science has been developed experimentally. It is against such objectives that it is being presently and continuously evaluated.

#### OBJECTIVES IN NATURAL SCIENCE

In the application of the ideas of Colgate's Committee on the Postwar College to the core course in natural science, the proper procedure was not immediately apparent to the organizing committee. Current social problems can be discussed at least to some extent without much background on the part of the student, but current problems in natural science seem like tasks for graduate students. One way out of this difficulty could be to return to an earlier period when science had not progressed so far, as suggested by President Conant. As he illustrates, the history of certain ideas or developments in science can be valuable for showing "the methods by which knowledge has been advanced in the last four hundred years."<sup>1</sup>

However, in planning a required course, student motivation is an important consideration. The committee feared that an entirely historical approach might fall short of its hopes, and the natural enthusiastic interest students have in contemporary

<sup>1</sup>James B. Conant, *On Understanding Science* (New Haven: Yale University Press, 1947), p. 17.

developments would go unused. Furthermore, the committee was unable to set down in black and white just what the major objectives of the course were to be.

Solutions—if not final solutions—of the uncertainties were found by experimentation. Problems from various points of view were prepared and tried, with the plan that each year as the course is given, new ones would be added or substituted. The question of whether the historical approach should be used has been answered separately for each problem. Some problems are predominantly historical; others make little reference to it. The criterion has been the estimate of what contribution we feel the history will make for the time devoted to it.

After the staff had taught the course for several months the most important objectives seemed to crystallize into shape. They have been expressed as follows: (1) to give the student experience in accurate and critical thinking and jolt him out of his habit of authoritarian learning; (2) to give him an appreciation and understanding of how natural science has functioned and does function to gain its results; (3) to provide him with a grasp of some of the important laws and principles of science. Naturally, in the limited time available we are quite aware of the small degree to which we can achieve these objectives. Yet we feel the course is a far greater intellectual *experience* for the students than the former surveys ever were, and that the students do gain some appreciation of what the methods of natural science are.

#### ORGANIZATION OF THE NATURAL SCIENCES

For the sake of course continuity, and because problems all too often spill over into other fields of science, it would have been advisable to disregard all divisions between the disciplines of natural science, but because few teachers are prepared to do such teaching without an inordinate expenditure of time and energy, this seemed impossible. Hence one term is devoted to problems in physical science and the other to problems in biological science, and the student may take either first.

If the course is to be an educational experience for the student it must be handled in small groups. We have found that sections no larger than twenty-five are manageable; twenty would be better. These small groups meet three times each week and one afternoon is set aside for other activities, at

which time all sections are brought together for a lecture pertaining to the problem at hand, supplemented by appropriate demonstrations and carefully selected motion pictures. Sometimes the afternoon is devoted to laboratory experience in small groups, and on other occasions students make a geological field trip or view the stars. Other afternoons are used for examinations in the course.

Colgate's experience with survey courses demonstrated the wisdom of having one instructor handle a section throughout the entire term, rather than having a series of specialists. Hence, this practice is being continued. The handicap of the instructor's limited background is more than compensated for by the continuity of approach and by the many threads of unity which he can weave through the various materials studied during the term. He also is able to know his students in a way he never could if he saw them for only a few weeks. The successful class meeting is neither a lecture nor a recitation of the traditional type. It consists rather, of an active exchange of ideas, the instructor assisting in clarifying concepts and encouraging students to judge explanations by the degree to which they fit observable facts.

The training of an instructor for such a course is no small problem. Even though we were fortunate in having a nucleus of those with experience in the former surveys who had obtained some familiarity with fields other than their own, the selection of a few topics for intensive study in several fields of science caused these experienced teachers to feel quite unprepared. This problem was and is being met by scheduling weekly staff meetings or seminars when over a cup of coffee instructors compare notes on teaching devices and successful approaches to specific teaching problems. They also discuss material to be used in subsequent class sessions, with the member in whose field the topic falls in charge. These staff meetings have been one of the most stimulating phases of the course as far as the instructors are concerned.

Obviously such a course as this can have no textbook. Each student obtains a set of mimeographed notes for his guidance, but most of his study is done in selected books on the library reserve shelf, of which there are enough copies to provide one book for each ten students. It is not always possible to find suitable source material. Some books are too authoritarian

and fail to explain the reasons for the facts stated; others, especially in biological fields, assume a knowledge of a large number of technical terms and esoteric information. When at all usable, translations or original writings are assigned for background, particularly when the history of a problem is being considered.

### PROBLEMS IN PHYSICAL SCIENCE

The course in physical science is built around seven scientific problems which are studied intensively. The first problem deals with the solar system. It is desirable that any well-educated person have a clear picture of both planetary motion and our place in the universe. This topic has the pedagogical advantage of requiring the use of a minimum of special concepts and unfamiliar terms. The visualization of relative motion from different points of view is about the most difficult task the student encounters. However, these advantages are secondary to the main virtue of the topic for our purposes, namely, the ease with which two alternative and conflicting hypotheses can be set up for explaining a group of scientific observations and their relative merits determined.

The conventional method for approaching this subject is the historical one. Certainly the history of this famous problem should not be omitted, and when skillfully handled it can be developed into a fascinating story. But in a course required of all students we have the difficulty of arousing interest when many of them may be quite cool toward science. Accordingly we have adopted a somewhat different approach, a synthetic one, which has turned out to be even more successful than we first hoped.

The problem is presented in the form, "Does the earth go around the sun or the sun around the earth?" All students have known the answer to this question for many years and they fail to see the point of bringing it up for discussion in a college course. The instructor explains, however, that he and the students are going to take that as a problem to explore according to accepted practices in physical science, that they will assemble their own observations either directly or by quotation from reliable observers, but that any inferences, inductions, hypotheses, or judgments will be made by the students themselves and not borrowed from others. Then to illustrate

how the method works he raises a prior question, "Is the earth flat or round?"—a sample problem which can be attacked in the first class meeting. The students are able to suggest a number of observations commonly used as evidence of the sphericity of the earth. The instructor's role is to point out what implicit assumptions are used in drawing the inference, and to show how several of the observations could perhaps be accounted for upon a flat earth, at least until further study and measurements are made.

A careful description of celestial motions is then attempted. The students are taken in small groups for a view of the evening sky. They are also assigned readings<sup>2</sup> which cover a greater span of observation than they can make themselves. When they are aware of the daily westward circulation of the sun, moon, and stars, a tentative hypothesis is proposed to account for these motions, namely, that the earth is rotating on the same axis in the opposite sense, eastward.

It is then suggested that some deductive test of this hypothesis would be valuable, if it could be found. At this point they are directed to descriptions of various effects of the so-called Coriolis deflection, best illustrated by a Foucault pendulum. The behavior of such a pendulum is also demonstrated in the afternoon lecture.

The next step is to consider the celestial motions still unexplained by assuming rotation of the earth. The most noticeable is that of the moon, which nightly shifts substantial distances in the sky, taking twenty-seven and a half days to return to the same position in front of the background stars. The hypothesis that the moon is revolving around the earth once in that time seems quite adequate to account for its apparent motion.

The sun also shifts, relative to the background stars, about one degree a day. This is not directly observable but can be inferred from the changing pattern of rising stars at sunset, or from other studies. By analogy with the moon, it is proposed that the sun revolves around the earth once a year in a path inclined 23 degrees to the celestial equator.

Attention is next directed to the planets whose motion upon the celestial sphere is not uniform like that of the moon and sun. They progress eastward most of the time but at certain

<sup>2</sup>The best source we have found for that purpose is Hogben's *Science for the Citizen*.

intervals they appear to stop and move westward, then move eastward again. The nature of these retrograde loops is made clearer to the students by having them plot the paths on polar coordinate paper. Successive telescopic photographs of Mars and Venus, for example, show substantial changes in apparent diameter coupled with partial or complete phase changes, suggesting that their orbits might be centered at the sun. With the proper choice of periods and relative distances it is possible to obtain retrograde loops which agree essentially with observed ones, by assuming that the planets circulate around the sun, *which in turn carries them about the earth.* This model is somewhat different, it might be pointed out, from the old Ptolemaic system of epicycles and deferents.

This description has been set forth in some detail to show that it is entirely possible to account for all the apparent motions in the sky upon a geocentric hypothesis! Why then, the student begins to wonder, do we so universally accept the heliocentric view. How can one distinguish between them? There are various procedures which can be used at this point. The instructor can point out that all possible hypotheses should be explored with equal vigor, and a search made for some discriminating test. Or he can suggest that much important information is still lacking, such as the relative distances, and hence sizes, of the celestial bodies. The fact that when the half-moon crosses the meridian the sun is setting indicates fairly easily that the sun must be many times larger than the moon or earth. When a study is made of the movement of two bodies about their common center of mass, it becomes apparent that the heliocentric hypothesis has some advantages. Furthermore, were the earth more massive than the sun, it should greatly perturb the planets in their orbits around the sun, since gravitation is assumed to be the central force holding all the celestial bodies to their orbits. Finally, there are two critical deductive tests, namely, aberration and stellar parallax, both due to motion of the earth in its orbit around the sun. These last effects have been observed but are extremely minute, of the order of a few seconds of arc or less, and historically were not instrumental in settling the controversy.

This development of the topic occupies the attention of the students for about two weeks. The discussion is sufficiently detailed and slow that the average student has no trouble in

following the many steps of logical reasoning involved. He has an appreciation, for the first time, of the nature of the problem confronting the observer of celestial motions, and is beginning to get a feeling for the distinction between observations and hypotheses.

At this point his attention is turned to history, starting with the earliest accounts of celestial motions. With the background of his own struggles for understanding, he has far more sympathy for Aristotle and Hipparchus in their misconceptions, especially when he realizes the additional handicaps of philosophical approach under which they worked. He speculates upon the failure of Aristarchus' heliocentric proposal to gain acceptance. When the Renaissance is dealt with, considerable attention is paid to the work of Tycho Brahé, not only because it was highly precise and systematic, but because Tycho adopted the very geocentric hypothesis developed above—the earth fixed with the sun revolving around the earth and the planets around the sun. Tycho had foreseen that the Copernican theory would require some stellar parallax. He sought for it with great care, and failing to find it he discarded the theory and proposed his own, which illustrated the use of a discriminating test with erroneous results.

In conclusion it is brought out that the general acceptance of the heliocentric theory began with Kepler's remarkable inductions from Tycho's careful observations, and that this theory became widespread three-quarters of a century later when Newton demonstrated that Kepler's laws were obtainable from the single hypothesis of universal gravitation. The observation of aberration in 1727, and the detection of stellar parallax and the prediction and discovery of Neptune a century later, served to establish the theory for all time.

It is not unnatural, after a careful exploration of the nature of the solar system, to speculate as to its possible origin. This is the second problem in the physical science part of the course to which about a week is devoted. This problem is in distinct contrast to the first one because of its very nature. The clues from which we can work are so meager and the lapse of time so tremendous that no hypothesis has yet been proposed which avoids serious objections. It troubles the students to discover that "science," which they have tended to regard as the modern oracle, is forced to admit failure in solving this

problem. It also bothers them, when they read about various proposed hypotheses, to find that different authors are not in entire agreement. This question is an excellent one for showing how hypotheses evolve and how they are tested. It also gives the students a feeling of having explored a small sector of the frontier of science.

The two problems from geology which we are currently using actually cut quite widely across the fields of astronomy, geology, and physics. One of them is concerned with such matters as the temperature and the composition of the interior of the earth. The other, a rather small one, would probably not be used except for the excellent source material which we have obtained permission to use. It is concerned with the origin of the "Carolina Bays." For the first day on this problem the students are asked to read an article from the *Saturday Evening Post* of September 9, 1944 which describes in vivid language how a huge comet composed of thousands of large meteors struck the earth and left these peculiar depressions, the Carolina Bays. The next assignment is another article on these same bays written by Douglas Johnson in the *American Scientist* of January 1944. Using this problem as a case study of methods of research, the author first develops the plausible meteoric hypothesis and then by careful analysis finds it unsatisfactory and searches for other explanations. The final solution he proposes is nothing like the spectacular one of a plunging comet, but a composite one involving several geologic processes working together.

It is continually stressed that the "scientific method" never works twice the same way, that the steps will vary from problem to problem, although some elements are nearly always present. For this reason we have deliberately chosen our list of problems from several fields to illustrate the variations of method. For example, astronomy is almost totally an observational science. Geology is also largely so, but at least the observational material is near enough at hand to be capable of close examination. In the fields of physics and chemistry, however, controlled experiment plays its greatest role and many hypotheses are couched in the symbolic language of mathematics. Since we felt that in a freshman course required of all students we could not utilize mathematics to any great degree, the selection of problems and the treatment of some

of those we use have been restricted, but in spite of this limitation we have had no difficulty in finding an adequate supply of good problems. It is tempting, rather, to try to squeeze in more than we can treat adequately. We claim no special virtue for the group we are currently using. Our plan to introduce at least one new problem each year will build up a pool from which to draw in the future.

One such problem, which involves physics largely and is centered around the kinetic theory of gases, is posed in the question: "Why does the temperature of the air decrease as one goes to higher altitudes?" It is necessary within this problem to devote some time to a study of properties of fluids, concepts of pressure, work, energy, and so forth. Then it becomes apparent that an adequate picture of the structure of a gas is needed. The kinetic theory is introduced hypothetically to account for the properties of a gas and thence the properties of the atmosphere.

A group of problems related to flight follow. They are: "How can man get up in the air? How high can he go? How fast can he go?" Then two weeks are devoted to the problem of combustion which is treated historically by showing how the phlogiston theory developed and how it was overthrown.<sup>3</sup>

The final problem of the term is atomic energy. The main defense for using this topic is the keen interest the students have in it together with its contemporary importance. Although it is not a single problem in the sense that many of our others are, we approach it historically, and we endeavor to carry through the study of atomic and nuclear structure as a series of problems, many of which were solved by now classical experiments (for example, Rutherford's scattering of alpha particles). The students seem to grasp the current "fluid drop" model of the nucleus without difficulty, and express some surprise when they discover that there is no great "secret" in the large-scale release of energy by this process. The last afternoon lecture also presents an opportunity to introduce some of the social and political implications of this scientific and technological development.

<sup>3</sup>This has been described in greater detail by S. J. French in *The Journal of General Education*, I (April 1947), 203.

## PROBLEMS IN BIOLOGICAL SCIENCE

As in the case of the physical sciences, biology is offered as a definite number of problems and the student is confronted by a set of puzzling situations, each of which is designed to arouse his curiosity and challenge him to find a satisfactory explanation. Since, ideally, the motivation for the exploration of a problem should be derived as much as possible from the student himself, particular care must be attached to the phraseology of the question by which each problem is introduced. A question which is too ingenuous or one which is too abstruse will produce initial indifference.

In order to introduce the general subject of evolution by means of a direct reference to a specific situation which is neither too technical nor too easily explained, the question, "Why does the body contain useless parts?" is used. Considerable interest is generated by first examining the assumption implicit in the question that the body *does* contain useless parts. How does one prove a part useless? Discussion of this point, using specific examples such as the well-known appendix, third eyelid, and coccyx, demonstrate the principle that proof in biology is exceedingly difficult—perhaps impossible—and that arrival at a high degree of probability is often all that can be accomplished.

Direct answers to the question about useless parts are based upon recollections of a high school course taken two to four years previously. Generally these answers suggest that the useless parts are vestiges of formerly useful structures which have degenerated through disuse. When this hypothesis and others which may be proposed have been formulated, the task of the students is to decide upon the kind of evidence needed to support their hypotheses and then to procure it by reading and logical argument. The students are referred to such works as Darwin's *Origin of Species* as well as to O'Toole's *The Case Against Evolution*—especially selections which question the validity of evidence based upon vestigial structures. The entire field of evolution is thus thrown open, since the changes producing useless parts cannot be divorced from all other changes which result in the origin of new species. Throughout the entire discussion, however, reference is made as frequently as possible to the original point of departure so

that a thread of continuity may exist and an answer to the original question may be attempted in the end.

The initial response to the question, "Does the blood circulate?" has proven, however, more apathetic. Students are apt to consider the answer to this question so well known and well established that the problem requires no further attention. Nevertheless, this problem has much in its favor for fulfilling the objectives of the course. The first step in treating this problem is a clarification of the meaning of the phrase, "circulation of the blood." Experience has shown that few college freshmen—although categorically claiming that blood does circulate—can make an analysis of the circulatory system in clear, general terms. For example, the mere motion of the blood is frequently mistaken for true circulation.

In dealing with this problem, the instructor may play the part of a firm disbeliever, and the student is urged to assume the role of an investigator attacking an original problem. Taking nothing for granted, the students are asked to plan a series of observations and experiments which will produce as large a body of evidence as possible in support of the hypothesis that the blood does circulate. Many of the steps in this series may be suggested by the students' reading in William Harvey and some may be their own. With such a plan in mind, the students are given considerable opportunity to carry it out. Demonstration dissections of several types of vertebrates and preparations of the sheep heart and lungs are supplied for careful examination. Considerable time is spent observing the flow of blood through the web of the frog's foot and through the three-day chick embryo. Living frogs may be used to trace the course of blood through the heart and major blood vessels. The students' own arms are available for carrying out Harvey's directions for locating the valves which prevent the backflow of blood in the veins. A number of movies which reinforce and extend the students' own laboratory experiences are shown at the general meeting. Considerable time is allowed for reflection upon the reading, discussion, and laboratory experiences and for the exercise of critical judgment. A student is thus provided with an opportunity to understand, in a way not otherwise possible, the several factors involved in the establishment of even so fundamental a concept as the circulation

of the blood. Incidentally, of course, a considerable amount of factual information is necessarily acquired.

Undoubtedly the biological problem which arouses the greatest degree of spontaneous interest is the one which deals with reproduction. This problem is primarily directed toward exploring the hormonal factors which control the very early development of the individual. As is inevitably the case in biology, considerable descriptive material must be included. It is difficult to speak of the functions of such structures as the ovary, the follicle, corpus luteum, and pituitary in intelligible terms unless the students are acquainted with the positions, anatomical relationships, appearances and, to some extent at least, the cellular structure of these parts.

The problem is treated by the historical method, although its history, in comparison with that of many biological problems, is relatively contemporaneous. The question of reading material which is comprehensible to the students is solved by George W. Corner's recent book, *The Hormones in Human Reproduction*. This book presents, in a very human and understandable way, a firsthand account of the progress of representative biological investigation—not as it should have occurred according to arbitrary scientific precepts, but as an actual case history illustrative of biology as it really operates. Much of the experimental work involved is described in sufficient detail to permit a considerable amount of critical discussion and appraisal. In following this account of the investigation of the role of the hormones in reproduction, a student's attention is directed to the many and often unpredictable variables associated with life which the investigator must constantly take into consideration, the way in which the results of previous work sometimes lead into sterile paths and the human incidents which constitute such a poignant part in the progress of science.

In the laboratory the students are given an opportunity to see the actual effects of sex hormones upon the vertebrate body. Frogs are injected out of breeding season after the method developed by Roberts Rugh so that it is possible to demonstrate ovulation and the passage of the eggs down the oviduct as well as fertilization and subsequent development. These observations are supplemented by the excellent motion pictures, *Fertilization Studied through a Microscope and Ovulation in the*

*Frog*, which show aspects of these processes which it would be otherwise impossible to demonstrate.

Although the biological problems of the course are separated from problems in physical science, there are many cross-fertilizations. In dealing with the basis of life, for example, its molecular level must necessarily be considered. This leads inevitably to a fair sampling of chemistry, especially in connection with proteins. Similarly, in connection with the problem of the circulation of the blood, some principles of the flow of fluids are necessarily referred to. As the course develops, this cutting across departmental barriers will undoubtedly increase.

The seven problems dealt with when the course began have been cut to six and there is a general feeling among the teaching staff that the number should be still further reduced in the future. A reduction to five or even four problems would allow still greater freedom in exploring the several ramifications inherent in each and would allow a greater degree of student participation in firsthand laboratory experiences.

In addition to those problems referred to above, three others are considered during the semester. One of these, "Can life arise from nonliving substances?" concerns the origin of life in recent times. As man's knowledge of life progressed from the level of the organism to that of the cell and finally to the molecular level, there has been a successive modification of his ideas about life's origin. As a result, the boundary between the animate and inanimate has become less clear. The problem leads inevitably to a consideration of the virus which seems to melt indistinguishably into the "twilight zone of life."

The problem in heredity, like that in evolution, is introduced by a direct question of fairly specific nature—"How is skin color inherited?" In this connection there appears an excellent opportunity to weigh scientific evidence with preconceived and often biased notions. Finally, the question, "How is the earth's food supply continually renewed?" introduces the basic process of photosynthesis and the central position which it holds among the major problems facing man today.

#### TESTING

An important asset derived from testing a student by quizzes and examinations is the additional understanding of the subject matter which he gains by the process. When he is confronted with a question to be solved or a situation to be ac-

counted for, he makes an attempt at supplying the desired answer. When that question is later discussed before the class, he not only learns the degree to which he satisfied the test, but he learns what his errors of judgment were. This trial-and-error process makes a strong impression.

An aspect of testing which is sometimes overlooked is the fact that the type or form of testing used will determine the actual objectives of the course to a greater degree than often realized. Students are quick to discover what type of preparation will yield optimum performance in terms of grades, and instructors are subtly influenced in the same direction. It is essential to have the objectives of the quizzes and examinations in as close agreement as possible with the basic aims of the course.

Testing by objective questions is being used increasingly. The advantages are well known, but their drawbacks come to light acutely in a course of this type. Obviously factual information as such, and without context, is of no value in achieving the aims of the course. Hence, questions of that type are inappropriate. Objective questions which test reasoning power and discrimination can be written, but they are extremely difficult to prepare. We have been making efforts in that direction, but are quite aware of the size of the unexplored areas. One successful type we have found presents a somewhat hypothetical situation and then makes statements, the validity of which the student must decide by reasoning and not by memory.

The following is an example of this type:

The following data apply to the planet Mars:

Period of revolution: 687 days

Period of rotation:  $24\frac{1}{2}$  hours

Mean distance from the sun: 1.5 times the mean distance of the earth

Diameter: 4200 miles

Inclination of equator to orbit:  $23\frac{1}{2}$  degrees

Revolution of larger satellite: W to E with 30-hour period.

Imagine yourself to be transported to Mars in a middle northern latitude, and that you defined the points of the compass in the same way we do upon the earth. Indicate whether the following statements are true or false.

The sun would rise in the east every  $24\frac{1}{2}$  hours.

The stars would rise slightly earlier every evening according to "sun time."

- The sun would appear to move westward in front of the background stars.
- The stars would appear to move across the sky in circular paths with centers close to Polaris (within about one degree).
- A "midnight sun" could only be seen in early summer for latitudes greater than 67 degrees.
- Meteors would never be seen.
- The planet, Earth, would go through a complete cycle of phase changes. Earth could never be seen at midnight.
- The moon would disappear from view behind the Earth every revolution.
- Jupiter would appear faintest when in the middle of a retrograde loop. The larger satellite would appear to rise in the west.
- An astronomer would find stellar parallax easier to detect than upon the earth.

Even if there were a multitude of excellent objective questions, we would not wish to use them exclusively. Both short, written answers and essays are quite worth the extra time they take to read. Many intellectual problems which the student faces are not necessarily outlined and clarified for him as they are in most objective questions. There is much merit in presenting the student with a fairly general situation and asking him to marshal whatever factual material he may have learned, adapting it to an explanation or evaluation of the case in point and supporting broad claims and generalizations with specific evidence. Perhaps that quality which most distinguishes an educated person is his ability to go beyond the acquisition of mere factual information, using this knowledge to deal with new situations and to form new concepts. It is this type of performance which we attempt to measure by asking questions of the type represented below:

A student wished to determine whether the effects of a certain chemical on the skin were cancer producing. He carried out the following procedure and obtained the results as stated.

First, he secured 20 mice from three litters born to three different sets of parents of mixed hereditary origin. The mice were all mature but of three different ages.

He shaved off a small patch of hair from along the left and right hand sides of each animal.

He applied one drop of the chemical from a medicine dropper to the shaved area on six of the mice, two drops to six others, four drops to six of the remaining number, and left the other two untreated.

Nothing unusual was noted for the next eight months.

At the end of this period, however, one of the mice treated with one drop was found to have developed mammary cancer, three of the mice treated

with two drops and two of those treated with four drops also had mammary cancer.

Neither of the untreated mice had cancer.

The student concluded that the chemical used on the skin of the mice was cancer producing and that the incidence of cancer was directly dependent upon the quantity of chemical applied.

Make a careful, step-by-step appraisal of the procedure and techniques used by the student, evaluating their scientific effectiveness in arriving at the conclusions drawn by the student.

### CONCLUSION

Although as yet we have attempted to draw only tentative conclusions regarding the value of the course, there is evidence that it is receiving increasingly good student response. More or less typical is the response of two students—one a prospective chemistry major, the other interested in medicine. Both were doing excellent work and were advised that they might pass up the second half of the course in view of their prospective plans. Neither was willing to do so since both felt that the course gave them a view of science not obtainable in the more orthodox courses. This feeling, if broadly substantiated, is heartening since the Postwar Committee took the attitude that the courses in general education should be of such nature that all students, regardless of background or proposed college plans, should derive profit and understanding from them. Furthermore, they should not serve either as prerequisites or as substitutes for more orthodox courses in the same area but should form, rather, an independent core of education.

We are coming to believe that the course provides an intellectual experience for the student worthy of the effort it costs the staff. Future efforts must turn more and more in the direction of developing additional techniques for student motivation and more active participation in his own education. If these ends are achieved the fundamental objectives of general education—better understanding and ways of thinking—can be met. Our present experimental effort is only a start in that direction.

## The Science Programs in the College of the University of Chicago

SOME TWO decades ago, as part of a major reorganization of the educational and administrative facilities of the University of Chicago, it was decided that a student ought properly to devote the first two years of his college work to the pursuit of a liberal education before starting specialized education in some field of his choice. General courses, or sequences of such courses, were accordingly initiated in the College in the areas of the humanities, the social sciences, the natural sciences, and English. The program in natural sciences consisted of two one-year courses, entitled, respectively, Introductory General Course in the Biological Sciences and Introductory General Course in the Physical Sciences.

It did not take many years of experience with this program to convince those who were interested in it that two years constituted too meager a period of time in which to accomplish the desired educational ends. In 1937 the College program was accordingly extended to include what is normally the last two years of high school. In the area of the natural sciences in this new four-year program, students who entered the College after two years of high school were required to take either a two-year sequence in the biological sciences (called Biological Sciences 1 and 2) followed by the existing Introductory General Course in the Physical Sciences (renamed Physical Sciences 3), or a two-year sequence in the physical sciences (called Physical Sciences 1 and 2) followed by the existing Introduct-

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The course in Biological Sciences is described by Merle C. Coulter, professor of botany and former chairman of the College Biological Sciences staff; in Physical Sciences, by Zens L. Smith, associate professor of the physical sciences in the College and secretary of the College Physical Sciences staff; in Natural Sciences 1, 2, 3, by Joseph J. Schwab, associate professor of the biological sciences in the College and chairman of the College Natural Sciences staff.

tory General Course in the Biological Sciences (renamed Biological Sciences 3).

In 1943 plans and experiments were started with a view to constructing a self-contained three-year offering in science for students who entered the first year of the College. From these plans and experiments emerged the sequence known as Natural Sciences 1, 2, and 3. The old Biological Sciences 1 and 2 and Physical Sciences 1 and 2 were abandoned, but Biological Sciences 3 and Physical Sciences 3 (less their numerals) have been retained.

Today a student may apply for admission to the College after two, three, or four years of high school, or after a year of college elsewhere. Once admitted, he is faced with the problem of passing fourteen six-hour comprehensive examinations covering a variety of general areas. From some of them he may be excused on the basis of placement tests he takes directly following his admission; upon completing the others, he is awarded the bachelor of arts degree. In the area of science, all students must meet the requirement of a comprehensive examination in mathematics. The course which prepares for this examination is Mathematics 1, plans for which were also initiated in 1943. Once this requirement is satisfied, those who entered the College after two years of high school complete their science requirement by taking the comprehensive examinations over the three-year program, Natural Sciences 1, 2, and 3; those who entered the College after four years of high school take the examinations over the two-year program, Biological Sciences and Physical Sciences. (Biological Sciences may be taken concurrently with Mathematics 1.) The relatively few students who enter the College after three years of high school are merged, insofar as the science requirements are concerned, with one or the other of the foregoing groups, depending upon the amount of mathematics and science they completed before entering.

The following two sections of this report on the science program in the College of the University of Chicago describe respectively the two-year program for students who enter the College after high school graduation (Biological Sciences and Physical Sciences) and the three-year program for those who enter after two years of high school (Natural Sciences 1, 2, 3).

## The Two-Year Program

### BIOLOGICAL SCIENCES

The introductory general course, Biological Sciences, is the only beginning biology course normally taken by students who enter the College after graduation from conventional high schools. It is therefore obliged to serve the interests of both the prospective nonbiology majors and the prospective biology majors. Since the former group is in the majority (roughly 75 percent) it is the primary obligation of the course to provide such biological training as is appropriate to general education. Under this limitation the course also attempts to provide a substantial biological foundation for the smaller (25 percent) group of students who plan to continue further in biology.

#### *Objectives of the course*

The guiding objectives of the course, Biological Sciences, have been:

1. To develop in the student an understanding of, a respect for, and some facility in, the application of the clear and unbiased method of thinking that characterizes, or should characterize, workers in the field of natural science. Experience has shown us that presentation of the so-called "scientific method" in terms of a battery of admittedly formalized routines (a practice which is apparently shocking to some scientists) leaves the student with a stronger impression and better grasp of the method than did the looser method of presentation that we used at first. The more formalized method facilitates the use of a number of clean-cut tests, and these tests go far in reinforcing the learning process of the student. The teaching staff hopes, of course, that students will apply their habits of thinking scientifically about classroom biological problems to the more general problems of their everyday life. If we possessed methods of judging the extent to which any such transfer occurs—and we have no such methods—we would probably be disappointed with our findings.

2. To familiarize the student with a good many of those biological facts and principles that a modern citizen needs if he is to make an intelligent and effective adjustment to the demands of life. The course makes no direct attempt to cover

"practical" biology. But, wherever possible, "practical" illustrations are used to support the principles that are being presented.

3. To develop in the student an appreciation and some understanding of the grand machinery of the organic world.

As a fourth possible objective the staff has contemplated cultivating in the student an aesthetic appreciation of biological objects and phenomena. On grounds of expediency, however, it has been decided that no teacher should force himself to serve this objective, but that every teacher should feel free to advertise the beauty and excellence of living things on appropriate occasions.

The course serves these several objectives fairly continuously through the entire year, but does not make use of them as rubrics in its subject-matter organization, which is, instead, as follows:

#### *Organization of the course*

The Autumn Quarter provides a survey of plant (three weeks) and animal (eight weeks) kingdoms in phylogenetic sequence. This gives the students a useful framework for reference, an appreciation of the history of living things, of phylogenetic relationship, and of the principles of classification. Only the more important groups of organisms are considered, and each such group is usually considered in terms of a single example.

The Winter Quarter provides a study of the human body in health and disease, involving frequent comparisons with the physiology of other organisms. This material lends itself well to an examination of experimental methods. It also provides quite a bit of useful information about health and increases the likelihood that students will refer to the best authoritative sources on health questions.

The Spring Quarter considers (1) unlearned and learned behavior, briefly; (2) evolution, genetics, and eugenics, at greater length; and (3) ecology, fairly briefly.

The course is scheduled on the basis of two lectures and two discussion section meetings a week. Usually about fifteen different lecturers are used in the course of the year. Most of these are specialists from the various departments of the Division of Biology.

Discussion sections of about twenty-five to thirty students continue through the year under the guidance of the same instructors. It is this corps of instructors that constitutes the permanent staff of the course. Operating under a "chairman" (rather than a "director") this staff meets frequently to plan course policy and administrative details, revises the *Syllabus* and the *Thought Question Booklet*, prepares numerous short and long practice tests and, with the cooperation of one of the assistant examiners, prepares the comprehensive examination.

#### *Text materials*

The *Syllabus* outlines the subject matter, makes citations of "indispensable" readings (as well as optional readings), presents lists of questions by which the student can test his mastery of the readings, and occasionally supplements the readings by additional prose passages.

The indispensable readings are selections from a rental set of eleven books that the student holds through the year. These books are of diverse origin, some having been produced locally to fit the needs of the course.

At the outset we recognized the necessity of reducing the amount of the technical terminology and descriptive detail that is conventionally presented in introductory biology courses. Even today most students emerge from high school conditioned to the belief that faithful memorization of long lists of terms and other details is the primary essential to successful performance in a course. If we were to parade before these students all the technical terms and details that have become associated with the various areas of biology, they would make such an effort to memorize these lists that little of their time, energy, and motivation would remain for adequate mastery of the more important principles, theories, and methods of analysis of science. So our lecturers as well as our discussion section leaders have made a continued effort to use a minimum of biological terms and to illustrate principles by only a few examples in those situations where the biologist is tempted to throw the whole list at the class (for example, endocrine glands, vitamins, digestive enzymes).

One of our educational experiments that has worked out happily has involved the use of the *Thought Question Booklet*. A few years after the course started we were forced to recognize

that we had actually fallen far short of attaining Objective 1. With all the vehement lip service that we had given to the importance of scientific thinking, it was still true that well over 90 percent of the student's time and energy through the year was devoted to a memorization of terms and descriptive material, together with a practically passive and rather unenthusiastic assimilation of some examples of scientific thinking that had been done by the scientists themselves. Surely the students needed a more extensive and active participation in scientific thinking of their own. They should be confronted with more new problems. They should be persuaded to solve these problems, or to try to solve them, by themselves, with the assistance of facts, theories, and thought processes already at their disposal. They should have as much as possible of the stimulating experience of discovering new ideas and new thought routines for themselves. And they should subsequently, with the assistance of the instructors, criticize their own thought procedures and recognize the extent to which they conformed to the fundamental disciplines of natural science. So we (gradually) produced our booklet of so-called "Thought Questions," which each student uses fairly continuously through the entire year. Much of our discussion section time, as well as large fractions of our various tests and the comprehensive examination itself, are now devoted to the thought routines that are suggested in this booklet. The students react well to this procedure, and have repeatedly testified that it makes the course more stimulating.

#### *Presentation of material*

From the first, most of the members of the permanent staff have felt that the course should be reinforced by an appropriate program of individual laboratory work. To date, physical and financial limitations have made this impossible for our class of over nine hundred students.

After some years of experience with the course the instructor usually inclines to the belief that the lack of individual laboratory work is less deplorable than he had felt at the outset. There are apparently two main reasons for this qualification of his opinion. One of these is that the course *does* provide some measure of the laboratory type of experience. A substantial battery of exhibits and demonstrations is pre-

sented each week in one or the other of our biology laboratories. A trip through one of these exhibits occupies from thirty minutes to over an hour, depending on the nature of the exhibit and the intellectual curiosity of the student. Also, our course has prepared an excellent set of eleven educational films (with voice) which provide rather ideal demonstrations of laboratory procedures in a manner directly related to the other activities of the course.

Another reason is that the very lack of individual laboratory work has impelled the staff to develop more new educational devices (objective tests, routines of the scientific method, thought questions) than would probably have been developed by a staff that was more fully occupied with the administration of individual laboratory work.

It is hoped that a day will arrive when the valuable educational innovations which have grown up in connection with this course will be, not replaced by, but supplemented with, a well-planned, modern, and preferably not too time-consuming program of individual laboratory work for the students.

It is difficult to judge, in any very objective terms, the success that the course may have had during its seventeen years of existence in serving the educational needs of the two groups of students for which it is intended: the prospective non-biologists and the prospective biologists. The vast majority of students have testified, both orally and on several printed questionnaires, that the course had made an attractive and effective contribution to general education. With very few exceptions, teachers of advanced biology courses have testified that students are better prepared for their work by Biological Sciences than by other introductory courses. While conscious of such testimonies, the staff of Biological Sciences has continued to be even more acutely conscious of needs for improvement of the course.

#### PHYSICAL SCIENCES

The introductory general course, Physical Sciences, was formulated nearly a score of years ago as part of the general plan described in the introduction to this paper. Early in the planning, those responsible for the course realized that if it attempted to serve the double purpose of providing technical training in each of several special branches of physical science and of giving to the general student that understanding

of science which should be part of the education of the responsible citizen, it would not succeed very well in the accomplishment of either of these aims. Since the announced purpose of the College is to provide general education, the choice was obvious.

### *Objectives of the course*

The course is designed to give the student an understanding of his physical environment. The objectives may be stated briefly as follows:

1. To help the student build for himself a unified picture of the physical universe as conceived by modern science.
2. To help him understand, and to give him some training in, the methods of science.

In order that the first objective may be attained, the course has been built around an integration of major ideas of science taken from the fields of astronomy, geology, physics, and chemistry. To attain the second objective, these ideas are analyzed critically for the method of their development. For example, study of the heliocentric theory of the solar system considers not merely what the theory states but also what phenomena are observed, how these observations lead to formulation of definitions and to pertinent assumptions which constitute the theory, how the theory in turn leads to certain deductions which are examined logically to establish the internal consistency of the theory, and how some of these deductions lead to predictions capable of experimental verification. The theory is then contrasted to the rival geocentric theory. This analysis leads to recognition of the interrelations of observations, definitions, assumptions, and deductions, and of their role in scientific procedure.

### *Organization of the course*

After a brief discussion of the scope and methods of the physical sciences, the course begins with a study of the earth and its relation to the celestial bodies. At this point, the student is brought gradually and in rather simple fashion to apply scientific methods to observations which he himself can make on any clear night, observations which have been common to all mankind from earliest times. Thoughtful consideration of the best explanation of these observations is encouraged by having the student read and compare excerpts

from such writings as Ptolemy's *Almagest* with chapters from the works of such modern astronomers as Bartky and Baker.

After about three weeks of relatively simple application of scientific method in the formulation of concepts relating to the shape and size of the earth and the apparent motions of celestial objects, the student devotes about a week to explicit consideration of the pattern of scientific thinking. Here are covered such topics as the joint roles of induction and deduction in scientific thinking, the nature of postulates, and a consideration of what we mean by scientific truth. This part of the course closes with a brief formulation, without lengthy discussion, of the chief topics which are to supply the raw material for the student's thought throughout the year: the heliocentric theory, the law of universal gravitation, theories of the interior of the earth and of the earth's age, the origin of the solar system, the kinetic molecular theory, the atomic theory, the electrical theory of atomic structure, the electromagnetic theory of light, and cosmology—the nature of the universe.

By this time, the student's consideration of moving planets, including the earth, has persuaded him that the effectiveness of further pursuit of such matters will be greatly enhanced by explicit study of how moving bodies behave. Repetition of Galileo's experiments leads to development of Newton's laws of motion, these being immediately applied to consideration of the solar system and celestial mechanics. A short chapter on the moon is followed by a discussion of the constitution, structure, and processes of the earth, together with consideration of theories regarding its origin and age.

Thus, while the first third of the course deals to a large degree with subject matter drawn from astronomy and geology, the aim is to identify, in the rather familiar context of these sciences, problems which will later be treated quantitatively by the basic sciences—physics and chemistry—and by mathematics.

At the beginning of the second third of the course, approach to the study of the basic sciences is made by further consideration of mechanics as the fundamental experimental science in which mathematics is applied to observations. Extension of the study of mechanics to include energy and work leads to its application to the phenomena of electricity and magnetism. Treat-

ment of heat and changes of state in terms of mechanics leads naturally to the kinetic molecular theory of matter. The atomic theory is then developed from a study of chemical reaction, the latter being exemplified in some detail by study of combustion and the acid-base reaction. Further consideration of electrical phenomena leads to formulation of the electrical theory of atomic structure, whereupon a systematic investigation of the relationships subsisting among the elements brings to view their periodic classification. These relationships are then explained in terms of the theory of configuration of planetary electrons.

After an introductory review, the third and final part of the course takes up the study of nuclear reactions leading to the theory of nuclear structure and the concept of atomic energy. Theories of light supply further information regarding the structure of matter and are then applied to further study of the stellar universe with particular reference to the structure of the stars. At the end, a brief recapitulation of the methods of science serves as a review of the entire course.

#### *Presentation of the course*

Throughout the school year, the student regularly attends two lecture-demonstrations a week, each followed by a discussion period. Both lecture-demonstration and discussion period are fifty minutes in length. As implied by the title, the lecture-demonstration usually consists, in considerable part, of experiments or other form of visual presentation of the subject matter. In addition, the student has numerous opportunities to carry out his own experiments and observations. During study of mechanics, heat, kinetic theory, magnetism, electricity, and light, experiments which each student may perform individually are set up in the laboratory. Similar provision is made for the performance of simple chemical experiments. The laboratory is conducted on an optional basis, and students without previous laboratory experience are particularly urged to participate in it.

Astronomical phenomena are excellently presented at the Adler Planetarium, located about five miles from the campus. Classes meet there for two lecture periods. Students are encouraged to attend at other times the free public lectures given there regularly, and to inspect the exhibits displayed in the corridors of the planetarium building. On the campus itself,

a six-inch telescope, with a competent instructor in charge, is available to the students from two to four nights each week. At least once during the year students and staff are given the opportunity to visit the Yerkes Observatory at Williams Bay, ninety miles north of the campus. Here they see in action the largest refracting telescope in the world as well as numerous other interesting and instructive activities and devices associated with modern astronomical research.

Geological processes and features are illustrated in a series of display cases in Rosenwald Hall, which houses the university's department of geology. Twelve cases of exhibits supplement the lectures, affording examples of common rocks, minerals, fossils, and structures that cannot well be demonstrated in the lecture room. At least once during the year an all-day field trip is planned to afford the student an opportunity to observe geological phenomena at first hand.

Many phenomena of scientific interest and their application to industry are demonstrated in the Rosenwald Museum of Science and Industry, which is on the lake front about half a mile from the campus. Students are strongly encouraged to make frequent visits to this museum both in groups and as individuals.

#### *Text materials and references*

A printed *Syllabus*, which supplies the outline for the entire course, is supplemented by references which are divided into two groups: (A) those intended for study in direct connection with the lectures of the course, and (B) those which present a fuller treatment than can be given in the syllabus or in the lectures, or which represent more advanced reading for especially interested students. Books of group A are purchased by each student or procured in a rental set at the University of Chicago Bookstore. Numerous copies of the books of group B are set aside for the course in the reading rooms of the College Library. Additions are made to Group B during lectures and discussion sections.

Group A consists of the following three works: W. Bartky, *Highlights of Astronomy* (Chicago: University of Chicago Press, 1935); C. Croneis and W. C. Krumbein, *Down to Earth* (Chicago: University of Chicago Press, 1936); R. J. Stephenson, *Exploring in Physics* (Chicago: University of Chicago

Press, 1935). In addition to renting or purchasing these books, each student is expected to purchase a copy of the paper-bound book, *The Birth and Death of the Sun*, by George Gamow, (New York: Penguin Books, Inc., 1945).

Group B comprises from twenty to thirty titles such as *The Solar System and Its Origin* (Russell), *General Chemistry* (Schlesinger), *Outlines of Physical Geology* (Longwell, Knopf and Flint), *Introduction to Mathematics* (A. N. Whitehead), *From Galileo to the Nuclear Age* (H. B. Lemon).

In addition to the *Syllabus* and the references of Groups A and B, each student purchases a mimeographed set of excerpts from the works of great men of science and a *Question Book*. These excerpts from original documents are analyzed critically for the method employed by the author and for the ideas they contain—the experimental evidence supporting these ideas, the assumptions made by the author, the logical consistency of the ideas, and their relation to other ideas of science. Problems from the *Question Book* are assigned during the lectures and discussion sections and frequently form the basis for class activity in these sections.

### *Summary*

Basic to every feature of the course is the understanding of science. Materials selected from various fields are chosen for their contributions to this end. Methods of presentation are evaluated from this viewpoint. The hopeful purpose of all those responsible for the course is that in the short time the student spends with us, whatever he may learn or fail to learn about science, he may gain sufficient understanding of the problems and the methods of science to make most effective any contribution which, as a citizen, he may be called upon to make to the solution of those problems.

## **The Three-Year Program: Its Foundations**

### NATURAL SCIENCES 1, 2, 3

In the crudest terms, the Natural Sciences program in the College of the University of Chicago is described immediately below:

*Its students:* the program is designed for any and every student without regard to a distinction between those students who intend to specialize in science, and those who do not.

*Its staff:* its staff is a group of eight to ten qualified chemists, physicists, and biologists, and two philosophers. The first responsibility of the staff is the planning and execution of a program of liberal or general education.

*Its methods:* it employs, for three academic years, three hours of discussion and two hours of laboratory a week.<sup>1</sup> Its students read, write, formulate and attack problems, meet in groups, with each other and with instructors, to discuss what they have seen or read, written or concluded. There are no lectures.

*Its materials:* it employs three large collections of scientific papers as its primary material. Each of these papers infers, deduces, induces, defends, attacks, constructs, analyzes, proposes, or in some other way moves from "data" to "conclusion." Each of them deals with some aspect, small or large, of a scientific problem. The author of each of them is a scientist known for his contribution to the solution of some scientific problem. Some of them are monumental contributions to science. Some are humble indeed.

*Its ends:* the language in which the ends of education generally, and the ends of this kind of program particularly, can be stated, has been so corrupted by vague reference, equivocation, and multiple ambiguity that a formal statement of ends is here postponed until a fuller description of the history, materials, and methods of the course imposes some restrictions on the meanings of the language of ends.

*Its general nature:* the program is a departure, not only from the traditional freshman science course of the current century, but also from the traditional survey course of the past two decades. It departs from the latter in preferring to spend four days clarifying the complex to spending one day in achieving equal clarity by suppressing complexities. In consequence, it departs from the survey course in preferring depth to breadth, and a few things thoroughly treated to many things touched upon and issued in tidy packages. It differs from the former in being as much concerned with the several natural sciences as ways of understanding, as it is with their subject matters.

<sup>1</sup>Demonstrations are substituted for laboratory work in the third year because of the nature of the subject.

It differs from both in refusing to adopt any one of the currently popular doctrines on the nature of science and scientific method. Instead it insists that the methods of science differ certainly from time to time and from field to field, and probably from problem to problem, and that, therefore, the sciences as ways of understanding cannot themselves be understood from sweeping or general statements alone, but only as exemplified repeatedly and variedly from instance to instance of scientific investigation.

#### *History of the development of the idea of the program*

A committee for study of the place of science in general education was formed in 1942 at the suggestion of the dean of the College with the present author as chairman. It included among others, the pioneer members of the present staff of the Natural Sciences Program: Messrs. Malcolm Correll, Benson Ginsberg, John Mayfield, Aaron Sayvetz. Each member of the committee had had from two to ten years' experience in general courses in science. Each member had been instrumental in his own course or courses in extending its purview beyond unqualified subject matter instruction. Each member had derived his extended purview from some emphasis on the general "liberal arts" of reading, writing, and thinking, and from a notion of conveying some special skills or abilities connected with what each of us was pleased to call "scientific method." It was not unnatural, therefore, that our seminar should have begun with an exposition by each of us of what skills and abilities we taught, how we taught them, and a defense of our radical and systematic. They included instances of apparent choice of skills in terms of the nature of scientific method.

It was not unexpected that we should differ as to what skills involved in science were both teachable and appropriate to a general education. It was most startling to discover, however, that we differed to an extraordinary degree on what constituted scientific method itself. This difference existed, not only between physical and biological scientists, but also among biologists, and among physicists. The differences themselves were pure contradiction as well as cases where the exponents were describing science in widely different sets of terms, thus indicating the existence of several distinct and apparently unrelated approaches to the question of scientific method.

Discussion disclosed that each of us could defend his own view of scientific method to his own satisfaction, and that a resolution of our differences could hardly take place through defense and attack upon our respective views. The level of good will was so high in the group, however, that rather than beg the question of the nature of science or disband in mutual dissatisfaction, it was agreed to proceed on the assumption that a better view of the strengths and weaknesses of our respective positions could be obtained if they—or something like them—could be examined, not as our own creations, but as the products of professionals in the field of methodology. This was undertaken. We attempted to lay aside for the time being our own conceptions of science and admit to consideration the doctrines to be found in a wide selection of documents by scientists and philosophers on the subject of the nature of science. We proceeded as students, not as professors. Our first task in each case was to attain clarity and agreement as to the meaning of the document under consideration; our second task was to defend the author's view (whether we *felt* agreement or not) by citation from our own experience of examples of scientific research, and a demonstration that these examples could be accounted for in part or in whole in the terms of the author we were then considering; our third task was to find in our adduced examples the matters or aspects which escaped the author's terms or apparently gave the lie to his formulation. This third task became easier as our reading became more extensive, since then, the terms of authors previously read pointed to aspects or matters which escaped treatment in the terms of the author under present consideration, and he in turn highlighted omissions by previous authors.

This procedure, carried on for some months, led to a number of insights concerning the relations of statements or doctrines *about* scientific method to each other and to science itself. These insights can be formulated as two critical statements and three positive ones. Those critical are:

*First*, many statements which had earlier appeared to us as meaningful now became visible as mere aphorisms, or as statements so general as to be largely meaningless without extensive qualification and specification. Among the aphoristic were such characterizations of science as "the attempt to seek the objective truth free of bias and emotion;" and as "the wise

consideration of known facts and current theories before attempting the solution of a problem," which is nicely contrasted to a third, that science "rigorously adheres to the facts of nature and eschews beliefs and dogmas based on human authority." To be taken more seriously, but still in the category of the truistic, are the many attempts to reduce science to a series of steps, for example:

- a. Observation of phenomena
- b. Determination of a problem
- c. Collection of relevant data
- d. Formulation of a hypothesis
- e. Prediction of previously unknown phenomena from the hypothesis

f. Test of the existence or absence of predicted consequences as a verification or disproof of the hypothesis.

Such step analyses are sound as far as they go but beg such questions as: (for a) what phenomena or what aspects of them should be examined?; (for c) what considerations constitute the criteria of "relevance," for example, the popularity or success of previous theory?; (for d) what kind of hypothesis? (see page 76); (for f) how does affirming a consequent validly increase the "probable truth" of a hypothesis taken as antecedent?

*Second*, a great many other statements were seen to be true if carefully restricted, but to be grossly misleading if taken as sole truths, or as referring to the whole or the most important part of science. Conspicuous among them were statements which characterized science as: the classification of facts (Pearson); knowledge of antecedent-consequent relations (Mill); precise measurement (Kelvin); laws of nature or empirical generalizations (nineteenth century physicists); knowledge of sufficient and necessary causes (Bernard); knowledge of forces as "causes" of phenomena (Newton); knowledge of the parts of the whole under investigation (Mill, other neo-Comteians, and other adherents to the doctrine of a "natural order" of sciences always read in one direction only, namely, social science, psychology, biology, chemistry, physics, mathematics).

The very fact that each of the cited examples above is true in part, or wholly true of *some* scientific investigations, or in some other way right but incomplete, foreshadowed our realization of the following three positive points:

*First*, there is not one scientific method, but several, differing certainly from field to field, and even, in many cases, from problem to problem.

*Second*, a number of doctrines concerning scientific method successfully avoid the aphoristic, the too-general, the vague, and beg as few questions as any doctrine on other subjects.<sup>2</sup> But, in view of the first positive point above, even a thoroughgoing and systematic single doctrine is misleading or meaningless unless taken in conjunction with a number and variety of examples. Examples if sufficient in number and variety, can indicate limitations of the doctrine by exhibiting exceptions to it. Or, the examples can achieve the same end by exhibiting the shifting meanings which must be assigned to the terms of the doctrine in order to make it "fit" the variety of examples of scientific investigation it is intended to explain. (It was this force-fitting of a doctrine to its data by equivocation, which we ourselves had employed to defend our personal views in the early stages of the seminar.)

<sup>2</sup>Of the number of useful doctrines, several are worth mention here. The Platonic view was found to be valuable with its emphasis on increasing unity of theory as a measure of progress, on the nonexistence of "objectively" irrelevant sets or classes of phenomena, and with its concern for words, statements, models, and even theories and ideas as mere images or reflections of reality. The Aristotelian view was found useful for science in general with its emphasis on the partial or "aspective" nature of the knowledge possessed by a given science of a given body of phenomena. The conception of species, of universal and particular, of the interrelations of matter and mechanism, with "end" or "value" in Aristotle were found especially useful in the biological sciences. The "as if" or conventionalist view of scientific theory as "convenient" and "useful" rather than "true" had its place. The logical positivist position with its formalization of the semantical problems involved in scientific theory, with its strong element of operationalism, and with its adaptation of the Platonic notion of unity was extremely useful. A proto-Kantian position with its notion of a furniture of the mind emphasizing a conceptual factor in scientific knowledge was also fruitful. An empirical emphasis on the raw data themselves and their uniformity was, of course, indispensable.

It should be noted, that the emphasis here is not upon the philosophic views themselves, but upon those aspects of scientific investigation which these views bring to the fore. It is necessary to point out this emphasis in order to avoid misunderstanding. Because the idea of the Natural Science program began with a re-examination of our philosophic positions, and because the course uses scientific papers, some of which are old, the program is occasionally mistaken for a course in the philosophy of science or in the history of science. It is neither of these. Our interest is emphatically centered upon the subject matter of the various scientific investigations studied. Our consciousness of possible philosophic positions on science and our use of original papers serve only to enable us to substitute for the traditional question, for example, "What is true about falling bodies?" the more complete question, "What is the current view of the behavior of falling bodies? How true is it? And how has it become known?"

This concentration upon the business of science is possible because the science program is part of a large whole (the College) which includes a history course dealing appropriately with the history or "sociology" of science, and a keystone course in the philosophy of knowledge which will deal at length with the philosophy of science.

*Third*, no one doctrine on the nature of scientific method, known to us, is sufficiently complete and multidimensional as to include all others. Therefore, such doctrines stand to each other and to the variety of facts for which they attempt to account, as alternative theories, each of which more adequately accounts for some aspects of the activities of scientists than any other, and no one of which accounts for all.

The preceding three statements in effect say that method is inseparable from content, if one wishes to possess a meaningful and undistorted view of method. How the scientist makes his many kinds of bricks from his many kinds of clay is hardly clear without seeing him decide on the kind of brick, the kind of clay, and without watching him gather the raw material, knead it, work it, shape it, and emerge at length with bricks, or occasionally a whole wall. This much became clear to us in a few months. Only continued study of theories of method, and scientific papers themselves, eventually forced upon us the realization that content was not only indispensable to *understanding* method, but that—shock to our semantical habits—method *had* a content. It became increasingly clear that if we segregated all that was not *process* under the rubric *content*, and ignored it for the purpose of understanding method, a distorted or incomplete view emerged of how the scientist "found" or "developed" knowledge. When we had exhausted the use of such words as deducing, inducing, generalizing, defining, observing, conceiving, imagining, classifying, correlating, there was still something missing. The "method" of science seemed to be constituted of something more than acts. It refused to be encompassed wholly by verbs; nouns were called for. There appeared to be a substantive element in method; there were not only acts of sense or mind or hand upon some raw material, but these actions were performed with tools, or devices of some kind. That there were tools for the hand and the senses, and what they were (the commonly recognized *instruments* of the laboratory) was clear enough. That there were also instruments employed by the mind as aids in its share of the scientist's work was not clear until continued reading of scientific papers involved in a particular line of investigation disclosed the existence of such intellectual tools and indicated the nature of them. That these tools of the intellect were ideas goes without saying. That they were particular, explicit ideas which the

long-term experience of each science had found especially fruitful as tools for the solution of its kind of problem did not become clear until the general notion that ideas were involved as an aspect of method sent us in search of the identity of the particular ideas which served this function in different subfields of science.

The ideas thus sought, and in many instances located with some confidence, are not the epistemological ideas such as "class" and "cause" (which, of course, are also tools of the intellect), but the strictly physical or biological conceptions of "particle," "field," "organism," "organ," "homologue," and the like. These are instruments or devices of method in the sense that it is in *terms of these* and similar conceptions that scientists *take hold* of their data and give them coherence and meaning. In more specific terms, this notion of ideas as an aspect of method consists in seeing that scientists do not merely "form hypotheses" in an unqualified sense, but that experience has shown them that certain kinds of hypotheses, those involving one or another of these conceptions, have proved fruitful in the past upon a variety of problems within a restricted area of phenomena and are likely to be fruitful again. Hence, when it comes to formulating a hypothesis, the scientist does not look everywhere for an idea, but looks first at the possibility of specifying certain familiar ideas of proved value so as to make them constitute a hypothesis for the data under consideration. He is theoretically free, of course, to choose any hypothesis he may wish; and, indeed, the daring choice of a new idea, a deliberate cutting off from the past and present of his science, may become the revolutionary new start in his field.

More often, however, the scientist is properly constrained by the usefulness of making the data of his immediate interest capable of relation with data involved in the rest of his science. This is most easily achieved if the data of immediate interest are subsumed under the same terms which embrace other data in his science. In short, in a physics where most other phenomena were understood in terms of particles with given values of diameter, mass, charge, elasticity, velocity, acceleration, position, direction of motion, or other property, it would be to the advantage of the science that new phenomena be embraced within this larger whole, by being understood in terms of some shift in the value of one or more of the assigned properties

of the particles, or, if necessary, in terms of a new particle with a new combination of properties, but in terms *other* than particle only as a measure of last resort.

Pedagogically speaking, then, a view of method in a science is not complete without knowledge of the principal notions which have been fruitful in hypothesis in that science. Such knowledge would include some idea of the potentialities and limits of these ideas in their general form. It would include a clear grasp of some of the major specifications of these ideas to particular purposes; for example, specifying the idea of "particle" by postulating certain relations, positions, motions, and so on, to constitute the molecule of an ideal gas in kinetic-molecular theory; or specification of a mass, charge, position, and motion of the electron of the Bohr atom. Above all, knowledge would include a clear understanding of why, in each of these instances, a particular set of properties was more appropriate than another to account for the data subsumed.

The question of the content of a program in science for general education was completed by shifting from science as a mode of investigation to the congeries of data included in science. Requestioning of our habitual criteria for choice of content yielded results similar to those described in the preceding section of this paper, but deviating less from common practice. It became clear that such slogans as "information useful to the student as man and citizen," "information enabling him to become an efficient consumer," "information enabling him to become effective in the principle areas of living" were vague or inadequate or both, but nevertheless pointed in directions which could not be ignored. Political and ethical considerations more meaningful (and therefore less capable of brief aphoristic expression) were required in order to include, inform, and complete these slogans.<sup>8</sup> Equally important, it became clear that criteria limited to political and ethical considerations were false guides unless thoroughly related to and restricted by the material to which they were intended to apply. That is, what is important in a science as viewed by the scientist can no more be ignored in the name of general education than

<sup>8</sup>For an outline of certain of these ethical and political considerations, see the author's paper in *Proceedings of the Institute for Administrative Offices of Higher Institutions*, pp. 42-52, The University of Chicago Press, 1941.

political and ethical considerations can be ignored in the name of loyalty to one's subject matter. Why such a synthesis of arbiter and arbitrator is necessary will be indicated in the final section of this paper.

Application of our elaborated criteria to their matter also yielded nothing unusual unless it were the sobering realization that in terms of political and ethical considerations alone (that is, concern for the future welfare and happiness of the students) many parts of the knowledge possessed by science were useful, but not one was indispensable, at least as formally purveyed in the course of a formal education. In the physical sciences, a high place in the hierarchy of usefulness could be defended for mechanics, astronomy, light and heat, the notions of atomic structure, and a crude outline of the variety and relations among kinds of matter. In the biological sciences, the subfields with obviously immediate human reference could similarly be defended: the psychologies of personality structure and of learning; human anatomy; the physiology of nutrition, of sexual development and maintenance; the identification, causes, cures, and preventions of disease; the theory of genetics and evolution and specification of the former to certain human traits. But alternatives to these are numerous and argument about them endless. The question of what *particular* physics and what *particular* biology, once some broad outlines are indicated, has much the same status as the question of what particular novels or plays should be read in a humanities program once it is decided that some novels and some plays shall be read.

When, however, consideration of what is important to the science be joined to ethical and political desiderata, the list shifts somewhat and indispensability becomes almost, if not quite, properly applicable to some subject matters. This is notably true of mechanics in the physical sciences because of its ubiquity throughout the theoretical structure of physics, chemistry, and astronomy. It is true for *some* taxonomic branch of biology (a notable addition to the list indicated in the paragraph above), for *some* physiology (including a biochemical aspect), for some anatomy, for some pathology. The list is longer for *biology* than for physics because of the disjunctiveness of the various branches of biology relative to the degree of unification found among modern physics, chemistry, astronomy, geology, and so on.

If, for the moment, we pretend that our sole and modest hope from a program in natural sciences for general education is that the students *understand something of science as a mode of investigation, and understand some aspects of the living and nonliving world*, it is clear that our conception of what it means for a human to "understand" anything is the pivotal question so far untouched in this discussion.

The committee's reading and discussion on the problem yielded a result as radical as the outcome of our analysis of the method of science in that at its conclusion we knew that our former views of the nature of "understanding" were inadequate to the reality. Unlike the case of method, however, we were not then able, nor are we able now, to formulate a systematic, responsible, and defensible statement of our view of "understanding." We have hold of a number of its bits and pieces; we know many of the components of it which have been alleged to be the whole; we can suggest the direction in which, we hope, the systematic statement will be found eventually. But the clear and organizing principle still escapes us.

It must suffice here, therefore, that we only suggest the nature of understanding. We shall do so in three ways: (1) by describing in general terms the behavior of one who possesses it by contrast with one who does not; (2) by describing an apparently indispensable component of the process of acquiring it; (3) by citing a few examples of questions which would attempt to discover its presence or absence in a student.

1. Bluntly put, a person *understands* a theory if and only if he can, *himself* criticize it, accept or reject it with reasons deemed cogent by an expert, or, if tendered an alternative theory with its defense, choose one over the other or state the impossibility of choice, with reasons deemed cogent by an expert. By contrast, the possessor of rote learning may "carry in his head all the principles, definitions, and proofs, and have it all at his finger's ends," as one philosopher has put it with somewhat mixed anatomical metaphor, "but if you challenge any definition, he does not know whence to take another, because he formed his own from the reason of another person. . . He knows only so much of it as has been given to him from outside."

2. A person understands a theory only if he *participates* in some way or other, in the processes of examining the data,

selecting and rejecting alternative notions, trying and testing, which went originally into the production of the theory. This "participation" need not be (and for practical purposes cannot be) a literal re-creation by the student of the products of great minds. But it can be the kind of "participation" which characterizes the act of appreciation of a painting or a piece of music. It can take place in the laboratory and the classroom if the student has access to the data, the alternative ideas, the reasons given by the scientist for his rejections and selections.

Such participation, be it noted, cannot be guaranteed to take place simply by placing the student, and the appropriate documents and apparatus, in physical contiguity. Discussion of the kind which stimulates, excites, and directs the attention and "participation" of the student is required.<sup>4</sup> Nor can any degree of ability on the part of the teacher guarantee that "participation" will occur in all the students at any given time.

3. The following few items, culled from one set of queries and one quiz, suggest some of the ways in which we try to probe for understanding. It is understood, of course, that perfect performance by a student on such items does not guarantee that he possesses understanding, even where the course has not sabotaged its own efforts by supplying the answers in lectures or textbook before the examination.

What property of waves which was useful or even indispensable to Galileo in discussing sound waves is rejected by Huygens as inapplicable to the vibrations which constitute light? Why is it considered inapplicable?

How would you reconcile Mayer's statement that ". . . motion cannot be annihilated; and contrary, or positive and negative, motions cannot be regarded as equal to zero. . ." with Huygens' science of impact in which positive and negative motion together may be regarded as zero, and similarly in Newton's Corollary 3?

When Mayer translates the maxim, *causa aequat effectum*, into the equation,  $c = e$ , does he regard the mathematical equation as a kind of metaphor, or as the exact expression of a quantitative equivalence? State the evidence for your response.

Would Mayer necessarily subscribe to Huygens' argument in the first new paragraph on p. 3 that since light is caused by motion, light must be motion? If Mayer would agree, state the principle on which he would base

<sup>4</sup>For a description of this kind of discussion see A. Sayvetz, "The Natural Science Program in the College of the University of Chicago," *Journal of General Education*, I (January 1947), 131-35.

his agreement. If he would disagree, state his conclusion to the premise: "Since light is caused by motion: .....

How would Young have had to revise his views if he had known of the Michelson-Morley experiments?

Sunlight coming from A passes through a circular hole B in screen S<sub>1</sub>, and then through the fixed prism C, producing a spectrum on screen S<sub>2</sub>. [This refers to a diagram not duplicated here.]

Newton states in the first paragraph of his paper on the spectrum: "The colors produced (by a prism) . . . (were) in an oblong form; which according to the received laws of Refractions I expected should have been circular." What must Newton have assumed about the incident beam A?

- A. The incident beam of light is unpolarized.
- B. The incident beam of light consists of particles.
- C. The rays in the incident beam of light are parallel, and should thus exhibit identical behavior if changed in direction only.
- D. Each ray in the incident beam of white light consists of many colors, each of a different refrangibility.
- E. The incident beam is, for all practical purposes, infinitesimally narrow.

[The above is followed by ten further items exploiting the diagram]

If Kirchoff had supposed that the phenomenon which he observed when light from a Drummond source was passed through a flame containing sodium, was a case of what Stokes termed "true internal dispersion," he might expect to see, in the resultant spectrum,

- A. Bright lines at any place in the spectrum.
- B. Bright lines in the spectrum farther toward the violet than the D-line.
- C. Bright lines in the spectrum farther toward the red than the D-line.
- D. A general increase of intensity of the spectrum farther toward the violet than the D-line.
- E. A general increase of intensity of the spectrum farther toward the red than the D-line.

In considering partial reflection from a refracting surface, Young states, "It is simplest to consider the ethereal medium which pervades any transparent substance, together with the material atoms of the substance as constituting a medium denser than the pure ether, but not more elastic." This view of the properties of transparent bodies, as compared with the properties of ether,

- A. Is maintained throughout the paper, as shown by the consideration of the phenomenon of diffraction, the differences in the diffraction of light, sound, and water waves being attributed to differences in the elasticities of the media involved.
- B. Is maintained throughout the paper, except in the case of doubly refracting transparent bodies, where Young accepts Huygens' explanation that there are two forms of waves in the body.
- C. Is totally rejected later in the paper, where Young shows that dispersion of colors by a prism requires that the waves of different breadths move with different speeds in the prism, because the glass is less elastic than the ether.

- D. Is maintained throughout the paper, since Young shows that dispersion of colors by a prism might be understood by saying that the waves of different breadths move with different speeds in the prism because glass is not perfectly elastic while ether is.
- E. Loses its meaning for Young when he realizes that dispersion can be accounted for only by assuming that the ether is a perfectly elastic, and therefore continuous, medium.

### *Realization of the program*

The means for practical implementation of the results of our deliberations was clear.

Our view of scientific method required that it be represented by a number of varied examples. Reports of scientific investigation were the obvious source of such examples.

Our view of method and of "understanding" required that scientific information itself be possessed in terms of data, their synthesis, test, and alternative formulation. Papers representing the progress of a scientific investigation were clearly the appropriate sources of such material.

"Understanding," as we defined it, required "participation" via interpretation, the weighing and criticism of evidence and experiment, the comparison and contrast of alternatives. These could be done only upon reports of scientific investigation.

The question, then, was whether several series of scientific papers could be so chosen and edited that each series simultaneously:

1. Presented intelligible pictures of varied scientific attacks upon a variety of scientific problems.
2. Displayed the development and varied application of several of the conceptions which have proved fruitful in hypotheses in the several sciences.
3. Unfolded a coherent statement of current or near-current views on the scientific problems treated. ....
4. Constituted, in respect of vocabulary, adequacy of description of phenomena treated, syntax, and so forth, materials intelligible to the student, yet sufficiently rich and complex to be appropriate to the process of "participation."

The results of our library search for such materials received their first, small-scale trials in 1943-44 and 1944-45. Some of our selections were successful enough to warrant further search. Others were partial or abject failures. Test and replacement continued through this period, and in 1945 the first

preliminary edition of papers for the physical science component of the course was given its official initiation with two classes of thirty students each. That material is now in its third revised edition. The biological component of the program was given its small-scale trials in 1944-45 and 1945-46. Its first preliminary edition appeared in 1946 and is now in its second revision. The remainder of the material entered its first preliminary edition in September 1947. There are now some 450 students in the program.

These periods of search and trial have not yielded perfect exemplars of the quadruple pattern of unities referred to above. Many of the individual papers, and a number of the series, however, serve their multiple purposes effectively. Those which do not are identified; the causes of their inadequacy are known in most cases; the search for replacements goes on. Where the subject-matter treatment *per se* is incomplete, and where connecting links between papers are required, we have learned the prudent use of traditional textbook material without damage to our primary purposes. Some of this text material we have written ourselves to fit it to our special purposes. Some of it comes from published texts.

The mode of treatment is exemplified in our most recently published series of papers on light and matter. The initial treatment of light is in terms of the conflict between the corpuscular and the wave theories of these phenomena. The former is seen in Newton; the latter is examined in great detail through treatment of Huygens' *Treatise on Light* in its entirety. This conflict is seen to be resolved in three additional papers. In Young's, "On the Nature of Light and Colors," the significance of interference phenomena to a choice between theories is found. In Fresnel's "Prize Memoir . . ." the successful explanation of diffraction in terms of wave-theory is examined. In a paper by Arago and Fresnel, additional evidence from the phenomenon of interference of polarized light is analyzed.

Accompanying the above are papers through which the students become familiar with certain other optical phenomena and their partial explanation, namely: heat radiation (Herschel); fluorescence and ultraviolet radiation (Stokes); Fraunhofer lines (Kirchoff); a successful formula for the wave lengths of the lines of the hydrogen spectrum (Balmer).

Matter and its relation to radiation is seen as a developing problem through papers reporting the discovery of new "agents," that is, Roentgen on x-rays, Thomson on cathode rays, Rutherford on alpha particles. These, plus the phenomena of wide-angle scattering of x-rays by metal foils, and x-ray diffraction, lead to Rutherford's model of the atom and Moseley's identification of atomic number with the plus charge on the nucleus.

Bohr's theory of the atom and its interaction with radiation follows, in the attempt to account for line-spectra and related phenomena.

Finally, Jean's "Report on Radiation and Quantum Theory" provides an account of the contradictions which lead to a systematic formulation and application of quantum mechanics and its relations to classical mechanics.

A similar account of other series of papers which constitute the physical and biological components of the program, and a detailed account of how each of the papers named above serve our other purposes is not appropriate here. The necessarily detailed description of how we employ the laboratory to relate the papers to their data, to illuminate the meanings of the papers, and to anticipate the problems of some papers also cannot be included here. An appendix which will supply lists of papers read and examples of laboratory work, reading guide questions, and examinations is in preparation and will be supplied upon request to the author.

#### *The relation of ends to means in the program*

The issues which, sooner or later, demand attention from men involved in general or liberal education are seen in:

1. Questions of ends. For example: Shall the course emphasize a "world view," or provide a survey of the "facts" and "principles" which constitute the sciences, or aim to provide a "useful" knowledge for future citizens, or develop certain assumed potentialities into "arts" or "skill"?

2. Questions concerning material. For example: What shall be the order of sub- and superordination of the various fields ~~within~~ the compass of the course? And within each field, what notions, areas, facts, and theories shall be included, and to what extent?

3. Questions concerning methods. For example: How much writing? What kind of reading? How many lectures? How numerous shall quizzes or discussions be? How much laboratory and what kind?

4. Questions concerning the student. For example: Shall the course be offered to everyone? To students who will not be specialists in the area covered by the course? Only to those who will be?

5. Questions concerning the teacher. For example: Shall he be a research specialist? A specialty-trained man with primary concern for education? Graduate students worthy of grants-in-aid? A man specially trained for general education?

As indicated, a small host of alternative answers to each question can be listed. The problem is to choose among these alternatives.

Two factors of monumental size account for most of the existent differences of opinion as to the "right" or "best" alternative. One of these factors is the wide variety of views, usually unsystematic and unexamined, on philosophic and psychological matters, which exist among physical and biological scientists. We have been concerned with this factor as it is involved in scientific method.

A second factor which contributes to differences of view is the number of ways in which questions concerning curriculum can be grouped and ordered. Different groupings and different orderings can in fact lead to quite different answers to the questions. Taking a grouping into ends, materials, and methods as a commonplace, it is obviously possible to begin with any one of the three. We shall note here the effect of beginning with materials, considering them as means, as against beginning with ends.

Professors with conventional doctoral training usually begin with materials. As a usual (though not necessary) consequence, their ends become those most pointedly suggested by the material, and their methods are determined by considerations stemming from the material and the materially determined ends. Other factors which might condition a judgment about ends, as, for instance, political, ethical, or psychological considerations, are thrust into the background. So also are considerations concerning the learning process or concerning levels of understanding which might have operated in the choice of methods.

Thus, mathematicians persuaded by one of the most pervasive characteristics of their material may conceive some kind of logical analysis or "logical thinking" as one of their ends. They may further define what they mean by "logical thinking" via their choice of analytic drill as the principle teaching technique, again because of the dominant role assigned their material, since such analysis is what the mathematician as such does to publications in his field. A consideration of the extent to which this kind of analysis is possible, and necessary or useful, upon other than mathematical materials, and a consideration of the extent to which material appropriate to such analysis will be encountered by students when they are such no longer, is suppressed or thrust into the background.

On another hand, professors a little touched by philosophy or pedagogy are inclined to begin with ends. The force of this ordering may be such that regardless of what other principles determine these ends, principles derived from the scientific subject matter of the projected course do not determine them.

This ends-to-means order creates a very peculiar problem to which the solutions are even more peculiar. A staff which has begun by formulating its objectives must now bring them to bear upon the particular subject matter (for example, the natural sciences) over which they have been given jurisdiction by an external agency. The subject matter was not chosen in the first instance to be appropriate to the stated aims. The reconciliation of a set of objectives developed out of context with a subject matter, with a body of material not chosen in terms of the ends, constitutes a dilemma which cannot be resolved successfully except by accident. The result of attempting to do so can be seen very quickly through an examination of a few instances of courses so planned.

One characteristic of many such courses is great disparity between the verbalized objectives and actual practices. Such disparity is now so frequent that to describe a course primarily in terms of its objectives is to invite a most cynical reception. The first and visible sign of some courses of this category is the great worthiness and grand scale of their objectives; they propose to teach their students to think, to make them responsible citizens, to cause them to develop into mature adults, to provide a philosophy of life, to teach appreciation of truth and

hatred of falsehood, to teach them to solve problems rationally and not emotionally, to understand the basic facts and most important principles of modern science. The unattainable and generally millenial character of these objectives is almost sufficient guarantee that they will appear only in the printed list and not in the graduating student nor even, to any great extent, in the methods and materials. If more evidence be required, it can be found in the frequency with which such courses find it possible to alter their lists of objectives without, to the same degree, altering the courses these lists of objectives allegedly describe.

Neither the charge of dishonesty nor the charge of uncriticalness frequently leveled at the staffs of such courses is necessarily justified. The objectives themselves are not dishonest nor necessarily naive. Neither, often, are the materials. The fault lies simply in the fact that the objectives are what the word "ends" usually signifies, namely, "intentions." These are good intentions. The editorial desks of educational journals are admittedly paved with them. The fault is, often, only the failure to realize that, however fine and grand certain objectives may be, (1) they are not good unless realized; (2) realization of any or all objectives through any or all subject matters is impossible; and therefore, (3) the proper objectives of a course in science (or in anything else) are those modest ones, which, abstracted from some grand, vague, and general list, are reduced in stature from the heroic to the merely human, and selected to be appropriate to the subject matter to which the course is assigned by tradition or the dean.<sup>5</sup>

In brief, the ends-and-then-the-means order of consideration lacks the flaws of the materials-and-then-the-ends order, only to exhibit flaws of its own. The solution to this either-or is obviously to see to it that each of the three terms, "ends," "materials," and "methods," be brought to bear upon the others; no one of them being permitted to assume the kind of independence which results in divorce from the others (as in the case of ends, in ends-to-means described immediately above); and no one of them being permitted such subordination to

<sup>5</sup>It is obvious, of course, that in a college without subject-matter distinctions, where there is only one big course, this prob'lem does not arise. There is, to this author's knowledge, only one such college in the United States.

the others as results in emasculation of its own principles (as in the case of ends, in means-to-ends described above).

It is in such a manner that our employment of the discussion technique as *means*; upon papers which in some way *move* from "data" to "conclusion," as *materials*; for the *ends* of "understanding" man's present view of some few aspects of our world, and equally for "understanding" a few aspects of physical and biological science as ways of understanding, have mutually determined, and been determined by, each other.

It is conceivable and entirely possible that these ends could be achieved by the above-mentioned methods exercised upon a different kind of material. It is conceivable and possible that the same ends could be achieved by lectures on history or philosophy coupled with reading of a textbook of chemistry or zoology. It is conceivable and possible, but not probable. For these methods, materials, and ends of ours have developed through a process of mutual determination and together constitute an organism of sorts. It is much more probable that the employment of a different method upon different materials would yield results capable of being signified by the same words we use to signify our ends, but that the meanings of these words would be different indeed.

## Science in the General Education Program at Harvard University

THE GENERAL education program at Harvard grew out of the discussions and recommendations in *General Education in a Free Society* published in 1945. There it was emphasized that general education is distinguished from special education, not by the subject matter considered but by method and outlook. The general education program is intended to bring the student in contact with many of the great problems which man has faced and to let the student see how these problems were solved by different men at different times. The student should develop a "feel" for the type of problems encountered in various areas of human activity. It is hoped that this will stimulate him to probe further into these problems, even after graduation. This type of study also appears to have great value for "cross-fertilization" between the several disciplines into which learning is segregated.

### PROPOSED COURSES

For many years Harvard has attempted to maintain a balance between broad and specialized learning by requiring a minimum distribution of courses among several fields. The general education program, when fully operating, will replace the existing distribution requirements. Of the sixteen courses required for graduation, six will then be in general education. One course in the humanities, one in the social sciences, and one in the natural sciences are to be taken in the first two years of college. The other three would be general education courses for more mature upper-division students, or approved departmental courses.

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Two introductory general education courses in science were proposed: one in the principles of physical science and the other in the principles of the biological sciences. Both are intended primarily to give the student insight into the fundamental principles of the subject and the nature of the scientific enterprise. The recommendation suggested that both courses should consist of lectures, individual laboratory work, and conferences. Each course should be designed and directed by a single individual, although it was suggested that occasional visiting lecturers might enliven the class sessions.

The course in the principles of the physical sciences should be built around a core of physics, materials from other sciences — chemistry, astronomy, and geology — being included when best suited to the objective sought. Any attempt to survey the physical sciences must be abandoned. Rather, selected problems should be placed in their historical context and developed as complete entities.

The course in the principles of biology should present an integrated view of living material, both plant and animal, with major emphasis on general concepts and the scientific approach to biological problems. Topics from various fields of biology and geology should be included where they contribute to the discussion.

Freshmen enrolling in these courses are required to have had only two years of secondary school mathematics and may have had no comprehensive science course. Yet many will have had four years of mathematics and one to three years of science. For that reason, two versions of the physical science course were proposed for students of widely differing scientific backgrounds. The principal difference between the courses will be in rate and rigor of presentation.

#### DEVELOPMENT OF THE PROGRAM

The faculty of arts and sciences of Harvard College voted in October 1945 to carry out the recommendations made in *General Education in a Free Society*, and approved the appointment of a standing faculty committee of twelve to organize the program. The faculty vote stipulated that not less than two nor more than four courses should be offered in an area. The diversity of approach for students of varied background provided by this action is apparently a unique characteristic of the Harvard program.

To provide varied courses for the ultimate program, a series of experimental courses was started in 1946. These are undergoing continual modification during the experimental period which is estimated to last five years. During this period the general education courses are optional; enrollments have been limited to only a small fraction of the eventual total. Radcliffe students may elect these courses and join in all sessions with Harvard students. In 1946 two courses in physical science and one in biology were offered. In 1947 the physical science courses were expanded to three lower-division courses: Natural Sciences 1, 2, and 3, and one upper-division course, Natural Sciences 11a, in addition to Natural Sciences 5 in biological science.

Natural Sciences 1 and 3 are intended for students with little background in science and mathematics. Natural Sciences 1 stresses the important place of science and technology in our lives. Natural Sciences 3, by contrast, stresses the historical development of science, the society in which advances were made, and the philosophical implications of scientific ideas. Natural Sciences 2 is for students with greater preparation in science and mathematics and in it logical rigor is stressed.

In 1947 President Conant gave an experimental course, Natural Sciences 11a, of one semester's duration, for upper-classmen. In 1948-49 this will be expanded to a full-year course, Natural Sciences 4, and offered to freshmen.

To aid in evaluating the courses, and to defend the students' interests in a new program that will become mandatory, the Harvard Student Council has polled students in these courses through extensive questionnaires. For the most part the general student opinion has agreed with the instructor's, but comments have aided in spotting difficulties. For courses given in 1946-47 the results of the first poll have been considered in planning the present revision. A second poll of the two-semester courses has not yet been made. For Natural Sciences 11a, a one-semester course, the results of the poll are reported on pages 107 and 108.

#### PRESENT SCIENCE COURSES

To provide the clearest statement on the planning, organization, and results of the present courses, the several instructors have prepared the sections which follow.

*Natural Sciences 1a and 1b*

This course is intended to meet the needs of nonconcentrators, the majority of whom have not had any previous course in physics, have had little mathematics, and are not expected to feel much enthusiasm for science. It was thought, therefore, that a purely practical and pragmatic approach, emphasizing the way in which science and technique permeate American life, would be more appropriate than an invitation to admire the wonders of science. It was expected that the lecturer's regard for the intellectual values of science would take care of that side of the subject without supplementary emphasis.

The introductory lecture reminded the students of the Industrial Revolution that they had studied in American history, and that one of the main factors in this revolution was the increasing amount of mechanical power available to every American. To understand this point it was appropriate to study scientifically during the first semester the different types of power sources made available during the nineteenth century: the steam engine, the internal combustion engine, and the water turbine, and, last, the role of electricity in the distribution and transmission of power.

The course started with a model of a steam engine in action and a qualitative explanation of its workings. It was then pointed out that the essential role of science consisted in replacing such a qualitative description by a numerical description in which, moreover, the magnitudes of the different physical quantities could be connected by permanent laws, regardless of the specific application investigated. Quantitative definitions were then given of work, power, power losses, and efficiency. Next, the so-called "simple machines"—the lever, pulleys, rod and crank, and so on—were studied. Then the conventional topic of heat was discussed with emphasis on the changes of state of water and the properties of steam. These notions were then applied to the pressure-volume diagram of the steam engine, and the values of efficiency corresponding to different diagrams were compared. The equivalence of heat and work was stated and demonstrated.

The origin of power being thus traced to the combustion of coal in the furnace, a collaborator from the chemistry

department, Leonard K. Nash, was called in. He presented the elements of atomic theory, the establishment of chemical formulas and equations, various examples of the oxidation-reduction and of the acid-base reaction, and introduced the chemistry of hydrocarbons. He then gave an outline of historical geology, with particular emphasis on the Carboniferous period and the origin of coal and oil.

This was followed by a description of the automobile engine, the Diesel, and the water turbine. At this point the course had covered those types of power engines which together accounted for almost all of the power used in the United States today, the source of power being either gravity or the combustion of coal and oil. To understand these engines the lecturer pointed out that a number of topics from physics, chemistry, and geology, which might otherwise have seemed quite unconnected, had been brought together.

Electricity, the lecturer pointed out, was not itself a source of power except in the negligible case of primary cells, but owed its tremendous importance to its efficiency in the transmission of power, and to the flexibility of the many types of electric motors. A short series of lectures on electricity was then given, beginning with the discoveries of Galvani, Volta, Oersted, and Ampere, leading as directly as possible to the explanation of the simpler types of a.c. and d.c. generators and motors. The analogy of the commutator with the D-valve of the steam engine and many other mechanical and electrical analogies were stressed.

A large number of topics had been covered during the fall term without meeting any one of the really difficult points of a standard first-year college physics course, such as the distinction of mass and weight, trigonometry, differentiation, and vector acceleration. It was thought that these difficulties, which in a course of the required level would have to be met sometime, would be more easily faced by students during the second term, after they gained confidence in themselves and in the instructor.

The second term began with the study of freely falling bodies, the inclined plane, composition of forces, and uniform circular motion. The elements of positional astronomy followed, with particular emphasis on the methods which enable us to measure the distances between the various bodies of the

solar system. Newton's universal gravitation was then deduced from Kepler's three laws on the assumption of circular trajectories. This was followed by examples of periodic motion, both mechanical and electrical.

In the next unit elements of electronics were presented. Dr. Nash followed with lectures on the architecture of the atoms of the chemical elements, the periodic table, and electronic valence theory. After a preliminary study of light and x-rays, Otto Oldenberg of the physics department presented the elements of nuclear physics, ending with an account of the discovery of atomic fission. A few evening lectures, in common with one or two of the other courses in physical science, completed the picture on certain points of cosmology and geology.

Although the emphasis and organization of *The Study of Physical World*, by Cheronis, Parsons, and Ronneberg, differed from this course, that volume served as a basic text. Except for short outlines of the lectures, practically no other printed or mimeographed material was distributed.

The course consists of three one-hour lectures illustrated with slides and demonstrations, and one two-hour conference period a week. Students were encouraged to ask questions during the lecture, and the instructor paused once or twice an hour at the end of some specific development to ask for questions when none had been forthcoming. The students easily adopted this technique, which they never abused, and the lecturer usually found that the questions either brought up or elucidated some point of general interest which would not otherwise have come to his mind. The conferences, for which the class of eighty was divided into five sections, consisted partly in answering questions, partly in solving representative numerical problems, partly in carrying out some demonstration with the students' cooperation.

Assignments consisting of four or five numerical problems, of a type discussed previously in conference, were given at intervals of one week or more. Two essays were written during the fall term, and one during the spring term. In every case the students had a choice among half a dozen subjects, ranging from purely descriptive ones to the historical development of some topic or the life and work of some sci-

entist, and finally to subjects of a more abstract or philosophical character.

The term grade consisted of a weighted average of the following: home assignments, term essays, two one-hour tests, one final examination. The final examination (of three hours, as customary at Harvard) consisted of seven simple numerical problems with a total credit of 70 and one essay with a credit of 30. Both the problems and the essays were identical in type to those worked out during the term. According to the instructor's evaluation — and this applies equally to the Natural Sciences course given in 1946-47 — the results of the final examinations were very satisfactory. A course of this type is in danger either of dealing in vague generalities without precise scientific basis, or of presenting technical material on too high a level for unprepared nonconcentrators. The final examination showed that the majority of the students were able to solve a problem of physics of medium first-year difficulty and at the same time to write a literary essay of good and often high quality, on a subject of scientific history or philosophy.

In the opinion of the instructor of Natural Sciences 1, only a minority of the nonconcentrators in science have an interest in the physical sciences as a cultural subject. At the opening of the course, the majority of the group either thinks physical science uninteresting or is frankly antagonistic to the scientific approach. These students take a course in science to meet Harvard's distribution requirements, and at present many choose a general education course rather than one of the specialized freshman science courses more or less by chance, or sometimes as a lesser evil.

The instructor first tried to break the students' attitude of indifference or negativism by bringing them to answer simple numerical questions. Once a student who, from previous experience, considered physics a hopeless subject has been made to feel that he, too, could do physics, it is an easy matter to carry him through the rest of a technical course. The antagonism of some literary students to science is often a reaction to the bombastic and cocksure attitude of many a scientist or engineer. If the student finds that the instructor never makes unjustified claims, stresses the limitations of present-day science and the number of its unsolved problems, the student

can be made to abandon his fancied or actual repulsion or distrust. It is then time to impress upon him the philosophical value of the empirical advances of science, a value all the more striking for not being based upon *a priori* assumption of the uniformity or the intelligibility of nature, the necessary character of physical laws, or the power of human reason. Portraits of Galileo and Newton hang on the walls, but Hume, Mach, and Bridgeman, although invisible, are no less present in the classroom. This approach has been found very well suited to students of the humanities and the social sciences.

### *Natural Sciences 2a and 2b*

The broad ultimate objectives of any physical science course in a general education program must be much the same as for any other. These objectives are conceived to be essentially:

First, to acquaint the students with the nature of scientific inquiry and with the role of science in society in order to fit them for intelligent response to the social problems which center around the progress of science.

Second, to acquaint the students with as many of the facts, concepts, procedures, and terminology of physical science as time permits on the assumption that elementary science is essential personal education in a scientific and technological age.

Third, to give the students training in logical thought, respect for disinterested inquiry, and an objective, experimental attitude toward problems of all sorts which can be approached scientifically.

In connection with the third objective it is realized that there is skepticism in some quarters regarding the contribution which physical science courses can give to the logical habits of the students. Nevertheless, this course attempts to maintain a high logical level in the belief that the minds of students are affected appreciably for good or ill by the logical standards which prevail in all their courses.

In order to reach these broad objectives, it is clearly necessary to confront the student with a variety of concrete scientific problems and show him just how they have been solved. In other words, the central job of the course must be instruction in technical subject matter. If this is well done, a relatively small amount of collateral reading and classroom instruction can give the technical matter the setting and

significance appropriate to liberal education. If this is not well done, no amount of talking about science is likely to give a genuine comprehension of what science is all about.

The choice of material has been dictated by the desire to maintain as much unity as possible in dealing with widely separated elements of scientific structure and also to gain maximum student interest. Since physics is the central physical science, it has seemed necessary to concentrate on that subject and sharply restrict the subject matter introduced from chemistry, astronomy, and geology. In order to give the student adequate historical perspective, the first term's work is devoted primarily to the development of physical science through the seventeenth century. Primary emphasis is laid on the development of the astronomy of the solar system and on the formulation of the laws of mechanics by Galileo and Newton. An attempt is made to bring out the conditions responsible for the scientific revolution of the sixteenth and seventeenth centuries and to describe the impact of the new science on intellectual and economic life of the time. Three lectures on geology are introduced in the discussion of the planets. The semester is brought to a close with an account of the law of the conservation of energy and its relation to heat.

The spring semester is devoted to the problem of the structure of matter, beginning with the kinetic theory of gases and terminating in a brief discussion of the problem of nuclear energy. In order to give an adequate background for an understanding of the high points of modern physics, such as the wave-particle dualism for radiation and matter, without an undue amount of dogmatism, it is necessary to carry the class rapidly through brief treatments of such topics as electrolysis, the Millikan oil-drop experiment, cathode rays, positive rays, electromagnetic waves, the photoelectric effect, x-rays, series spectra, Bohr's theory and its relation to chemical valence, radioactivity, and artificial nuclear transformations. In such a rapid survey it is necessary to keep historical references to a minimum. Time limitations make the pedagogical problem a difficult one which is undertaken only because it seemed probable that failure to capitalize on the present widespread interest in atomic energy would produce a sense of frustration among the better students.

Our text has been Krauskopf's *Fundamentals of Physical Science*. This book is well written, but not wholly satisfactory because the material covered does not fit very well into the special emphasis of the course. Mimeographed notes are distributed from time to time to help students with subjects which are treated too sketchily in the text. Assignments of collateral reading have included Aldous Huxley's *Science, Liberty and Peace* and portions of the following: Ptolemy's *Almagest* (mimeographed); Galileo's *Sidereal Messenger* (mimeographed); Randall's *Making of the Modern Mind*; Conant's *On Understanding Science*; and Wendell Johnson's *People in Quandaries* (applied semantics). Additional collateral reading will include portions of Gamov's *Atomic Energy in Cosmic and Human Life*.

Stephenson's *Exploring in Physics* has been used as a problem book. Problems are handed in nearly every week, but they are simple and do not play as important a role as in the ordinary introductory physics courses.

The course schedule involves three demonstration lectures and one two-hour conference-laboratory period a week. The latter is used in a flexible way for discussion, answering questions, quantitative demonstration experiments, and individual laboratory work of the conventional kind. On the whole, we tend to use demonstration experiments in preference to individual laboratory work. This procedure is particularly adapted to a course in which a large proportion of the students have been exposed to a high school course in physics. By using the demonstration technique we can take all of them through experiments which are advanced enough to be interesting to the most sophisticated.

We have used visiting lecturers to advantage in geology, chemistry, and astronomy, although the historical material on the astronomy of the solar system was taught by the regular instructor. Two or three written exercises dealing with material in the collateral reading have been assigned and have proved very stimulating.

For evaluating the results of our instruction we have depended on conventional tests and examinations. The central problems of instruction are the maintenance of student interest (which cannot be done if the material is not clearly presented) and the business of keeping up with the schedule.

It takes no tests to judge our success in dealing with these problems.

### *Natural Sciences 3a and 3b*

The purpose of this course is to give to students who do not plan to concentrate in any of the scientific fields a basic understanding of the principles of physical science, and to introduce them to the basic concepts, theories, and laws by means of which physical scientists explain the major phenomena of the external world. In distinction to the other two courses in the physical sciences, Natural Sciences 1 and 2, this course places a greater stress on the historical background, on the personalities behind the individual discoveries, the intellectual and social climate in which discoveries were made, and the philosophical background and implications of the major scientific ideas.

Students are expected to read a selected number of original texts of scientists as well as secondary sources of two kinds, modern historical comment and contemporaneous comment. A considerable amount of mimeographed and lithoprinted material is distributed to the students; other reading is assigned in books kept on our reserved shelves. The basic science reference text is *The Study of the Physical World*; but the students are also expected to read the whole of a short book on the history of science, F. Sherwood Taylor's *Science Past and Present*. From time to time, the students are also required to write historical essays and solve numerical problems.

The course begins in historical chronology with the following topics:

1. Anthropological considerations, primitive man and nature, science and magic.
2. The beginnings of exact science, the mathematics and astronomy of the Babylonians, methods of observation, the Saros series, and so on.
3. The contribution of the Greeks, idea of general laws, these laws discoverable to man, expression of laws in number form.
4. Greek and Hellenistic astronomy, Aristotle, Eudoxus, Hipparchus, Ptolemy. The major features of the Ptolemaic system, the satisfactory explanation of retrograde planetary

motion, the measurement of the radius of the earth, and early attempts to determine constants of the solar system.

5. The devious circuit of science in the Middle Ages, the contributions of the Arabs, the revival of learning, the achievements of Copernicus.

6. Galileo and the telescope, the contributions of Tycho and Kepler, the acceptance of the Copernican system.

7. At this point the students know that there are several unsolved problems about the Copernican system: the failure to find an annual parallax of the fixed stars, the failure to explain why birds are not lost as the earth moves rapidly through space, why a ball thrown straight up falls straight down. Questions of the latter type lead to our study of mechanics.

8. At this point students are required to read Galileo's *Sidereal Messenger* and Kepler's comments on it. Then, in order to relate the course to other studies, a long essay is assigned, based on Galileo's book and also on a choice of a portion of Milton's *Paradise Lost*, Dante's *Paradiso*, Aristotle's *On the Heavens*, and Donne's *Ignatius, His Conclave*. The essay topics include Dante's description of the moon compared to Galileo's (Was it only the new instrument, the telescope, that separated Dante's and Galileo's views?); Milton's discussion of the Copernican and Ptolemaic systems (How familiar was Milton with Galileo's discoveries?); Aristotle's views on the heavens contrasted with Galileo's.

The first portion of the course has been described in some detail because it shows just how the solar system provides an astronomical base for the historical development of science up to the seventeenth century. The next topic, mechanics, begins with the Aristotelian analysis of motion, the new ideas in the later Middle Ages, and a detailed analysis of the work of Galileo, Newton, and Huygens with a short digression on statics and forces. This second unit ends with a discussion of universal gravitation and the final synthesis of celestial and terrestrial mechanics. Students now read selections from Newton (the various prefaces to the *Principia*), a portion of Macclaurin's *Newton's Philosophical Discoveries*, selections from Randall's *Making of the Modern Mind*, and Carl Becker's *Declaration of Independence*. This reading, plus selections

from Galileo's *Two New Sciences*, provide the basis for the second essay: on Newtonianism.

The remaining unit, which completes the first semester, is devoted to heat and the kinetic theory of gases. The first unit, positional and solar astronomy, bring the student in time to the seventeenth century; the second unit, Galilean and Newtonian mechanics, brings him to the eighteenth century. The third unit, heat and the kinetic theory, extends the applications of mechanics and takes the student through the eighteenth century and into the nineteenth.

The second semester begins with topics from late eighteenth and early nineteenth century science, electrostatics, the idea of field and potential; then it goes on to the phenomena of electric discharge in gases, the identification of cathode rays,  $e/m$  determinations, and Millikan's oil-drop experiment. Stress is laid on electrostatics and on electric and magnetic fields; chemical, magnetic, and calorific effects of the electric current are discussed only briefly and chiefly in terms of their application to electrical measuring instruments.

The second unit of this semester is devoted to elementary chemistry, the idea of pure substance, early theories of combustion, the work of Lavoisier, elements and compounds, atomic theory, atomic and molecular weights, families of elements, the periodic table, ions in solution, the electron configuration of atoms, and the energy in chemical reactions (no evidence is given for the fact that the mass of atoms is concentrated in a positively charged nucleus; the students are told that evidence for this will be given later).

The third unit is optics, including rectilinear propagation, early ideas of waves and corpuscles, refraction, diffraction and interference, spectra (and their classification) the photoelectric effect, the quantum theory, the corpuscular theory of light, and the Bohr theory of the spectrum of hydrogen.

The fourth unit of the second semester is devoted to nuclear physics: radioactivity, alpha-ray scattering, evidence for the existence of neutrons, the structure of the nucleus, isotopes, artificial radioactivity, and uranium fission.

The last unit is devoted to the application of physical principles to the determination of the nature and structure of the earth.

While there are very few individual laboratory assignments for students, there are a great many group or demonstration experiments (with quantitative results) done by the instructor or his assistant in the weekly two-hour conference section. In addition to stressing the historical development of the sciences, great emphasis is placed on the source of our knowledge: those experiments that provide the basis for our statements. Furthermore, distinction is constantly drawn between experimentally observed facts and our theoretical interpretation of them. Attention is constantly called to the fact that the great discoveries come about in a variety of different ways.

One-hour examinations and the usual three-hour final, plus the papers and problems, provide a means for evaluating the students.

#### *Natural Sciences 5a and 5b*

This course deals with a selected number of aspects of biological science which are believed important for the understanding of living things generally and of the biological nature of man. Material has been chosen to illustrate certain characteristic problems, methods, and achievements in biological science rather than to attempt a new synthesis within or beyond the confines of this already large area. The structure of the course is topical rather than chronological. It is attempted to show that the topics considered involve matters of general interest or importance, and that biological science in the course of its development has come to have a particular contribution to make to them. The idea of man as a biological entity in a biological setting is an implicit thread running throughout most of the course. Much of the rich descriptive and comparative material of plant and animal science is sacrificed in order to give emphasis to principles and to the more analytical aspects of biology. It is assumed that the subject matter chosen can be made to speak for its own importance, provided that it can be related to existing, latent, or engendered interest within the student.

Although not necessarily so labelled in the course, the topics considered come in the following divisions of the subject matter of biological science: metabolism, nutrition, internal integration, reproduction, development, inheritance, evolution, ecological relationships, and aspects of behavior.

Moment's *General Biology for Colleges* is being used for some of the background reading, with additional assignments in a variety of comparatively nontechnical books such as: Kermack and Eggleton, *The Stuff We're Made Of*; Carlson and Johnson, *The Machinery of the Body*; Gerard, *Unresting Cells*; Dunn and Dobzhansky, *Heredity, Race, and Society*; Shapley (editor), *A Treasury of Science*; Romer, *Man and the Vertebrates*; Rickett, *The Green Earth*; Rahn, *Microbes of Merit*; Elton, *Animal Ecology*; and Allee, *Social Life of Animals*.

In the laboratory meetings, use is made of a considerable range of biological material with little distinction between exhibits, demonstration experiments, and individual work. No serious attempt is made to develop technical proficiency; laboratory work, whether performed individually or otherwise, is regarded as essentially illustrative of the subjects treated in other parts of the course.

Lectures, assigned reading, laboratory work, and discussion meetings are all employed in the course. There are special hazards as well as advantages in each, and there is no evidence of methods of instruction uniquely suited to the purposes of general education. The course consistently makes use of written (nonobjective) examinations in which it is sought to obtain a literate exposition both of fact or principle and of the implication or application of such knowledge. Examinations are regarded as a mode of instruction as well as a means of obtaining a grade for report to the registrar's office.

Minor changes in the content and arrangement of the course have been made as a result of the first year's experience. A textbook is required this year for the benefit of having at hand for each student a reasonably readable basic source of information. Outstanding problems concern the effective organization and exploitation of discussion meetings and their relation to laboratory work. As every science instructor knows, these problems are perennial and many-sided.

#### *Natural Sciences 11a*

The course, *The Growth of the Experimental Sciences*, was given in the autumn of 1947 by President James B. Conant at the request of the Committee on General Education. This course grew naturally out of the thought-provoking discussion presented in his *On Understanding Science*. Since it was defi-

nitely an experiment, and the president of a large university has many obligations, the course was limited in its trial version to one semester. A natural sequel was offered by Kirtley F. Mather, professor of geology, as Social Sciences 13b, *The Impact of Science on Modern Life*.

The basic hypothesis in this course was Mr. Conant's contention that a "feel for science" could be developed through intensive study of case histories drawn from the times when organized science was beginning. Then the number of bits of information that could be focused on a particular problem were relatively few and for that reason the solution of problems, which in retrospect seem rather obvious, called for the same scientific insight as current problems.

This course was open to upperclassmen who had not taken physics, chemistry, or Natural Sciences 1 or 2 while in college. Such a prerequisite restricted the enrollment to 166 who had but little interest in physical science. Of the students enrolled, 74 percent had taken school physics, and 54 percent chemistry; some had taken both. Of the 166 enrolled, 102, or 66 percent, were veterans who therefore were considerably removed from their secondary school science courses. Government and economics were the major fields of 53 percent of the class. One-half of the students expected to go into business or the law. Teaching, surprisingly enough, with 16 percent, ranked third in vocational interest. Because the students had taken no physical science recently, *The Study of the Physical World* was used for background information.

The course consisted of three lectures and one additional hour of section meeting each week. There was no laboratory work, but demonstrations were performed in the lectures and frequently in the section meetings. Six cases were presented to all students and a seventh was optional for replacement by an essay. These cases and the main objectives developed through them are described below.

*Case 1*, Pneumatics, was developed through the works of Galileo, Torricelli, von Guericke, Pascal, and Boyle. Twenty pages from Boyle's *New Experiments Physico - Mechanical, Touching the Spring of the Air . . .* were photostated and distributed. Additional reading was assigned in *Masterworks of Science* edited by J. W. Knedler, Jr., and in *On Understanding Science*. This case emphasized the development of a

conceptual scheme from experiment, the overthrow of earlier ideas, and the alternative ideas reflecting the prescientific era. With Boyle appear the difficulties of experimentation in the first stages of exploration, the measurement of variables, the control of variables, and the revolutionary results of improved techniques.

Two additional lectures were devoted to science in the seventeenth century and the origin of the Royal Society. The slowness of spread of science before the scientific academies was emphasized, and the slight effect of science on mechanical arts during the early stages of science was made clear.

*Case 2*, James Bradley and the Aberration of Light, was based on photostats of Bradley's paper in the *Transactions of the Royal Society* in 1728 and notes on the life of Bradley. Seven lectures were given by F. G. Watson. This case permitted further development of the importance of measurements and a knowledge of their inherent errors. It also emphasized the caution and patience required to obtain precise measurements and the necessity of isolating and controlling a great number of variables. Bradley's work also supports the statement that "chance favors the prepared mind," shows the difficulties of following up unexpected observational results, and illustrates the scientific intuition required to clarify confused theory and observation. As background material there was an account of the Ptolemaic system, the slow acceptance of the Copernican theory, and the relation of this theory to the cultural development of the seventeenth century.

*Case 3*, The Rise and Fall of the Caloric Theory, was developed through the papers of Black, Rumford, and Davy in the *Source Book of Physics*, and of Lavoisier, photostated chapters from *Elements of Chemistry*, 1789. This case illustrated how a conceptual scheme, the caloric theory, may be useful in correlating many phenomena and fruitful in many ways, yet be subsequently discarded. Even so, the old scheme still has some uses, as in the "flow of heat." The slow influence of the new concept of heat was illustrated by the history of the steam engine.

*Case 4*, The Phlogiston Theory, was based mainly on Lavoisier's writings, with the addition of letters from Priestley and Cavendish. This case reveals that a well-established conceptual scheme is hard to overthrow and that such a scheme is

not abandoned in the face of unreconciled experimental results, but only by appearance of a "better" scheme. The need for quantitative experiments again appears. Furthermore, a revolutionary new scheme generally "explains" hitherto obscure phenomena. Yet a successful new synthesis may contain characteristics soon to be discarded, although believed by the proponents to be essential (Lavoisier and the caloric theory). The personalities of Lavoisier, Priestley, and Cavendish deserve comparison.

*Case 5*, The Rise of the Chemical Atomic Theory, was a natural sequel to Case 4. Writings of Dalton, Gay-Lussac, and Avogadro show the continuing nature of scientific development and how new concepts are built on older ones. The value of speculative reasoning, when related to experimental facts, is evident because the conceptual scheme can be considered as only a means of relating experimental facts and essentially untestable postulates. No concept when new is likely to be complete or based entirely on sound reasoning. An incomplete or inconsistent scheme may, however, be very fruitful for years before undergoing modification (note the use of the incorrect formula for water for two generations). Phrases like "the atomic theory" have little meaning unless related to experimental observations; compare Democritus and Dalton.

*Case 6*, The Foundations of Dynamics, involved reading from Galileo, Aristotle, Benedetti, and others. In six lectures by T. S. Kuhn, the importance of Aristotle's dynamical synthesis was shown and the gradual development of its questioning clarified. The importance of the postulations of Galileo were then contrasted with the previous attempts to describe the crudely observed (retarded) motions of bodies. The importance of social activities (unfortunately, warfare) as a stimulus to investigation appeared. The culmination of the dynamical synthesis in the work of Newton was described and illustrated by reference to celestial mechanics.

A midsemester paper on "Science and Society in the Seventeenth Century" was required. This was a comparison of the controversial writings: *The Social and Economic Roots of Newton's Principia* by B. Hessen, *Synthetic Philosophy in the Seventeenth Century* by C. E. Raven, *The Growth of Thought in Society* by M. Polanyi, extracts from the *Novum Organum*

by F. Bacon, *Science and Social Welfare in the Age of Newton* by G. N. Clark, and *The Life and Works of the Honorable Robert Boyle* by L. T. More.

During the reading period, about two weeks at the end of the semester, two alternative procedures were offered. Students wrote a paper on the tactics and strategy of science reported in the *Life of Pasteur* by R. Vallery-Radot. Or they attended a series of lectures by T. S. Kuhn on the relationship between science and mathematics with reading from Einstein's papers, *Foundations of Mathematics* by M. Richardson, and *Symbolic Logic* by Lewis and Langford. Boolean algebra served as an example of pure postulational mathematics and led to the postulational character of Euclidean geometry. The similar postulational bases of non-Euclidean geometries were mentioned; then the apparent contradiction between Poincaré's and Einstein's descriptions of space were used to illustrate the potential difficulties when postulational mathematics and observational science were fused.

The final examination consisted of four parts: (1) discussion of certain cases, (2) simple problems in mechanics and chemistry, (3) some attempts to evaluate the scientific sophistication of the students, and (4) questions on the reading period work.

The instructors are loath to claim an unparalleled success; a number of modifications in timing and emphasis have already been planned for next year.

A questionnaire of 65 items was circulated by a committee of the Student Council in December during the sixth case on motion. Replies were obtained from 84 students (50 percent) who ranked slightly above average in the course and somewhat above the college average. They did not find the reading excessive, although 75 percent claimed to be doing all or nearly all the reading. No correlation appeared between mathematical preparation and either interest or success in the course.

Somewhat to the chagrin of those giving the course, the primary source material was not rated as highly important. Secondary sources, such as Conant and Randall, were preferred by many students. In agreement with the instructors, almost all students felt that a summarizing quiz or essay should be based on each case.

Lectures were reported as extremely popular, much more so than the section meetings, readings, and essays. It must be borne in mind that none of the instructors were experienced in holding discussion sections, but they were experienced in presenting varied material to sizable groups. Yet the section meetings were considered satisfactory. The students were overwhelmingly opposed to individual laboratory work (which had not been required of them).

An interesting agreement with the views of the proponents of the course regarding historical cases appeared. When asked whether they would prefer cases drawn from more modern fields, even though this would have meant a less complete treatment of the scientific notions discussed, the replies were: 35 percent, yes; 50 percent, no; and 15 percent, undecided.

On the case histories themselves it was clear that the presentation of the caloric theory was a complete failure. The discussion of motion (incomplete when the questionnaire was circulated) was rated low. Pneumatics and the phlogiston theory rated high, with the atomic theory third.

The case on Bradley rated as both highly interesting and highly uninteresting—opinions were decided. Admittedly this is a difficult case and will be handled differently upon repetition, but the good showing confirms the instructors' judgment that it is a valuable case to present.

In the opinion of 80 percent of the students the course was either successful or highly successful; 13 percent expressed no opinion, while 7 percent considered it a failure. In interest the course rated high; about one-half of the students felt it was more interesting than most courses. As an experiment the course may be considered to have been reasonably, but not completely, successful.

#### GENERAL CONCLUSIONS

Although the present courses are still experimental and undergoing change, they have evoked considerable enthusiasm and interest among the students who formerly shunned science.

Individual laboratory work has diminished during the two years of experiment. Instructors in the physical science courses appear to be of the opinion that group demonstration with active student discussion can achieve as much as individual laboratory work for students not concentrating in science.

This agrees with student opinion determined through polls by the Student Council. In the biological course, Natural Sciences 5, some individual laboratory work is welcomed, possibly because the objects and phenomena to be observed are small and have previously been beyond the normal experience of the students.

At weekly meetings the instructors in science discuss common problems and their proposed plans. Evaluation of the courses remains primarily with the individual instructors, for as yet no comprehensive testing and evaluation program has been organized.

## The General Biology Course at Stephens College

THE PHILOSOPHY of Stephens College places students' needs central in the educational program. The individual student and her problems constitute the accepted point of attack in planning courses and in teaching procedure. On the basis of his studies of the activities of women, Charters<sup>1</sup> identified seven areas of need. These are: (1) communication, (2) physical health, (3) mental health, (4) civic relations, (5) aesthetic appreciation, (6) consumer knowledge, and (7) development of an integrated philosophy of living. Since science is a service field which enters into most of these areas, a course in science has been included among the basic courses developed at Stephens to meet the student needs.<sup>2</sup>

### DEVELOPMENT OF THE COURSE

The General Biology course draws from all fields of science the materials selected as being of most value in dealing with human problems. It is not designed to prepare students for advanced work in science, but rather to fulfill a service-survey function for those who do not plan to major in science or go into science-related professions. It also has an orientation value for students who are uncertain about a vocation in science. The course is an elective, but it satisfies the laboratory science requirement for graduation at most of the colleges and universities to which Stephens students transfer.

After experimentation with the mosaic type of survey course, and also with a survey based on subject-matter principles, some ten years ago efforts were begun to build a basic science

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<sup>1</sup>W. W. Charters, "The Stephens College Program for the Education of Women," *Stephens College Bulletin*, Education Service Series, No. 4, January 1938.

<sup>2</sup>For a more complete description of the program of education based on this study, see R. I. Johnson, editor, *Exploration in General Education* (New York: Harper and Brothers, 1947).

program designed specifically to meet student needs. Instead of establishing a new course, however, the general biology offering was progressively modified to fulfill this function.

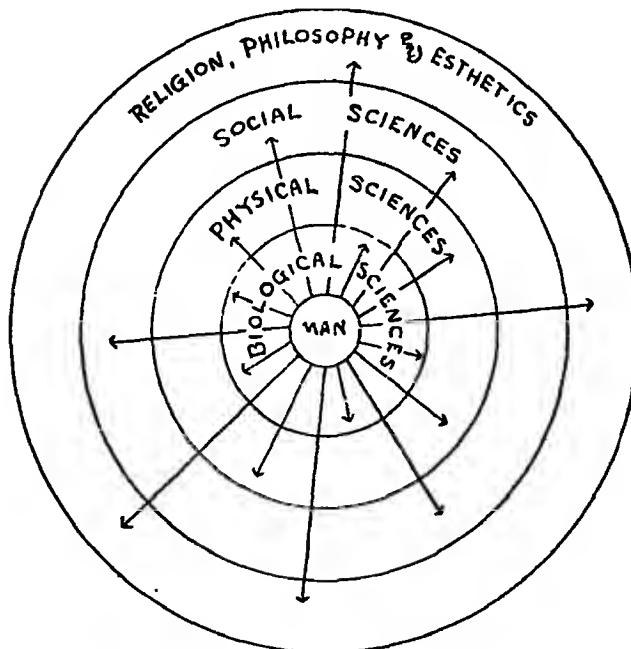
This development has been largely a matter of evolution. In the beginning, the course consisted of a core of subject matter selected simply on the basis of the instructor's judgment, dealing principally with zoology and human physiology, together with much of the laboratory work that ordinarily goes with elementary biological science. This was supplemented with a relatively large proportion of student project work, based on biological and biologically related library material. Student problems, both in the projects and in class discussions on the core material, were emphasized from the beginning. Later the original core material was abandoned altogether, and the course for several years was based entirely on student project work. This was not entirely satisfactory, however, because the values inherent in group work were lost, and areas of common need were sometimes neglected.

In developing a science course to meet a specific situation it is necessary to adopt an objective approach to the question of what it should include. Therefore, after several years of general experimentation a research study<sup>3</sup> was undertaken for the purpose of identifying functional areas in the field of science at the level of the general student. This study was designed to furnish a basis for the development of a new body of core material, related to student problems—those which exist now, and those which are likely to present themselves in the foreseeable future. Two sources of data were drawn upon: first, material which had been selected by students for project work in the course, chosen freely from science and science-related fields on a needs-interest basis; and second, science and science-related material included during a representative period of time in periodicals of a semitechnical and popular nature. Since current scientific literature at the lay level not only reflects present science problems, but through both news content and advertising also anticipates future ones, this appeared to furnish a very good indication of the frontiers of functional science, where present needs are being met, and new ones are likely to develop.

<sup>3</sup>W. C. Van Deventer, "Organization of a Basic Science Course," *Science Education*, XXX, (October 1946).

Although this study furnished the basis for the organization and content of the general biology course as it is at present, the evolution of the course has continued. Any description of it, therefore, is in the nature of a cross-section taken in mid-stream. Research to determine the validity of the present program, and looking toward possible improvements, continues each year, carried on both formally and informally by all of those who work with the course. This is supplemented by committee work in which the instructors compare, and when possible, correlate their results.

### Subject Matter Relationships in a Functional Man-Centered Science Course



the arrows represent human problems, rooted in the biological area, because man is a living organism, but extending outward into other areas

### DESCRIPTION OF THE COURSE

General Biology at Stephens College has become a man-centered course in functional science. Since man is a living organism, human problems are deeply rooted in the biological area. In dealing with these problems, therefore, a very great deal of biological material is necessarily included. Materials from other sciences are also necessary, as well as those from the areas of social science, philosophy, and aesthetics.

In all cases the criterion of what to include in the treatment of a problem lies in the nature of the problem, and not in any desire or necessity to cover subject matter or survey a particular field. Actually in the treatment of human problems the biological field is well surveyed, and many areas of the physical and social sciences are dealt with or touched upon. This coverage, however, is not an end in itself, and is strictly incidental to the work of the course. In the accompanying diagram the arrows represent human problems, while the concentric circles represent the areas of knowledge into which these problems may take a student in search of solutions.

The broad objectives of the course are:

1. To provide an understanding of those phases of science which effect the individual as a person, and in her family and community relationships;
2. To provide an understanding of the place of science in society;
3. To provide an understanding of the scientific attitude and method, insofar as they can serve as tools in dealing with everyday problems of living;
4. To furnish a foundation for the building of an adequate world-view.

In the light of these objectives the general viewpoint of the course becomes a consideration of man in relation to his environment, insofar as this involves science and science-related materials. This relationship includes three major phases, the first of which is readily divisible into two, making four subdivisions altogether:

- A. Man in relation to the living world
  1. Man in relation to other living organisms
  2. Man's body as a community of cells, tissues, organs, and organ systems
- B. Man in relation to the things that he uses

### C. Man in relation to the ideas that shape his actions

Certain carefully selected basic principles run through all of the material presented. These principles are those which tend to unify all science, and to extend beyond the limits of science into the area of problem-solving in everyday living. Eight of these basic principles or generalizations appear to be the following:

1. *Principle of objectivity.* The scientifically trained person cultivates the ability to examine facts and suspend judgment, not only with regard to scientific data, but also in relation to everyday experiences.

2. *Principle of simplicity.* When two alternative explanations of a phenomenon are presented, the scientifically trained person chooses the simpler, more mechanical, and more widely applicable one.

3. *Principle of uniformity.* The scientifically trained person assumes that the forces which are now operating in the world are those which have always operated, and that the world as we see it is the result of their continuous operation.

4. *Principle of predictable behavior.* Natural phenomena behave in a consistent manner which makes it possible to describe them in terms of scientific laws, and to predict results when the circumstances are adequately known.

5. *Principle of intergradation.* Within classes of natural phenomena there is continuous variation of individuals, and related classes grade imperceptibly into one another.

6. *Principle of practicality.* In any situation involving competition among units of varying potentialities, those which work best under existing circumstances tend to survive and perpetuate themselves to a greater extent than those which work less well.

7. *Principle of interrelationship.* Organisms and events are most meaningful when they are studied in relation to the environment or circumstances which surround them.

8. *Principle of continuous change.* Not only the present forms of animals and plants on the earth, but all of the things that life touches, have come about as a result of the operation of continuous change.

This list of eight principles is, of course, not complete. The reader will observe that the first three principles have to do with the attitude of the observer, while the last five deal with

the nature and behavior of the things observed. Further thought and experimentation will undoubtedly bring other principles to light. The list as it stands, however, is useful in helping to formulate the scientific point of view for the general student.

These principles are taught through the study of selected core material, through consideration of current scientific developments, and through work on actual problems brought forward by students during the progress of the course. All of these elements, however, are oriented in relation to the central emphasis: the relation of man to his environment.

In practice this means that each of the four subdivisions of man's relation to his environment is broken down for teaching purposes into a number of problem areas. These constitute the basis for the actual teaching units of the course. Each includes one or more subject-matter generalizations or "core ideas." At present there are fourteen of these problem areas which have been identified. They, with the core ideas which they contain, and a brief outline of the subject matter which is included in them, are listed here in relation to the four environmental subdivisions:

A. Man in relation to other living organisms

1. Animals and plants

*Core idea:*

- a. Animals and plants living in the same area are interrelated with one another in their life processes and form communities.

*Subject matter:*

- a. Animal-plant communities
  - (1) Interrelationships of organisms
  - (2) Responses to physical environmental factors
  - (3) Ecological succession and climax communities
- b. Outline of the classification of animals and plants

2. Man in relation to animals and plants

*Core idea:*

- a. Man is a member of the animal-plant community with which he lives, and is dependent on it.

*Subject matter:*

- a. The man-dominated animal-plant community
- b. Domestic animals and plants
  - (1) Improved breeds of animals and plants
  - (2) How they have been created and improved
- c. Foods
  - (1) Sources and processing
  - (2) Evolution of food habits

- d. Applied ecology
  - (1) Soil erosion
  - (2) Conservation problems

B. Man's body as a community of cells, tissues, organs, and organ systems

3. Food requirements

*Core idea:*

- a. The body needs definite quantities of certain food elements that are drawn from the environment.

*Subject matter:*

- a. Proteins, carbohydrates, and fats
  - (1) Body requirements
  - (2) Dieting
- b. Vitamins and deficiency diseases
- c. Mineral salts and water

4. Body functions

*Core ideas:*

- a. The body possesses an elaborate mechanism for processing oxygen and food substances, transferring them to the cells where they are used, and carrying away waste products to the organs where they are eliminated.
- b. The structure of organs and organ systems is significant and understandable only when it is considered in relation to the functions which they perform.

*Subject matter:*

- a. Maintenance systems: digestion, respiration, circulation, and excretion
- b. Assimilation and uses of foods

5. Biological basis of behavior

*Core ideas:*

- a. Normal behavior is based on normal functioning of the nervous and endocrine mechanisms.
- b. Consciousness and thinking involve complex interrelations within the cerebral cortex which arise as a result of immediate sense impressions, past experiences, and internal stimuli.
- c. Mental disorders may be due to structural defects in the nervous or endocrine systems, or to a breakdown in their normal functioning resulting from adverse environmental stimuli.

*Subject matter:*

- a. Central nervous system: its parts and their functions
- b. Endocrine glands and deficiency diseases
- c. Conditioned responses
- d. Factors in human behavior
- e. Mental disorders

6. Reproduction and development

*Core ideas:*

- a. The functions of the reproductive organs, the development of the embryo, and the processes of growth all take place as a result of the action of finely balanced internal factors.

- b. The development of embryonic structures can be explained mechanically on the basis of differential growth rates which result in inpocketings, outpocketings, foldings, thickenings, and cell migration.

*Subject matter:*

- a. Human reproduction
  - (1) Male and female reproductive organs and their functions
  - (2) Endocrine physiology of reproduction
  - (3) Outline of human embryonic development
- b. Reproduction in lower forms of life

**7. Heredity**

*Core idea:*

All organisms become what they are as a result of the interaction of heredity and environment.

*Subject matter:*

- a. Cell division
- b. Mechanism of heredity
- c. Mendelian crosses
- d. Human hereditary traits
- e. Eugenics

**8. Health and disease**

*Core idea:*

- a. Disease is a result of unbalance in the body, due either to failure of the organs to function properly or to invasion of the body by parasites.

*Subject matter:*

- a. Parasitic and nonparasitic diseases
- b. Disease-producing organisms
- c. Body defenses against disease
- d. Drugs in relation to disease
- e. Habit-forming drugs
- f. Specific diseases: cancer, tuberculosis, venereal diseases, children's diseases

**C. Man in relation to the things that he uses**

**9. Man's communication mechanisms**

*Core ideas:*

- a. Man possesses special structures for utilizing energy in the form of sound and light for communication.
- b. Man has worked to eliminate space and time as limiting factors in communication by transferring light and sound patterns to new media which can be interposed between the original source and the receiving sense organs.

*Subject matter:*

- a. Sense organs
- b. Vocal mechanisms
- c. Sound
- d. Light and other electromagnetic radiations
- e. Extensions of man's communication

- (1) Writing and printing
- (2) Telegraph and telephone
- (3) Sound transcription
- (4) Radio and television
- (5) Photography and motion pictures
- (6) Principle of transference of pattern

**10. Man's uses of energy**

*Core idea:*

- a. Man's upright posture and prehensile forelimbs have made it possible for him to evolve as a tool-using animal, and adjust to his environment by utilizing increasingly greater supplies of outside energy.

*Subject matter:*

- a. Man's skeleto-muscular mechanism
  - (1) Significance of the upright posture and prehensile forelimbs for brain development and tool-using
  - (2) Skeletal changes made necessary by the development of the upright posture
- b. Energy
  - (1) What energy is
  - (2) Forms and transformation of energy
- c. Extensions of man's energy uses
  - (1) Simple machines
  - (2) Complex machines as a part of modern man's environment: steam engine, gasoline engine, diesel engine, electric motor, jet propulsion, rocket motor
  - (3) Atomic power and its implications

**11. Man's uses of materials**

*Core ideas:*

- a. Atoms consist of limited numbers of extremely minute particles, having a definite relation to one another, but with relatively vast areas of space between them.
- b. The combining powers of chemical elements are based on the number of electrons in the outer energy levels of their atoms.
- c. The wide variety of synthetic products which chemistry has contributed to modern man's environment depends primarily on the versatility of the combining powers of the element carbon.
- d. Man's increasing knowledge of the properties of matter and synthetic substances has made it possible for him to utilize a progressively wider range of materials in adjusting to his environment.

*Subject matter:*

- a. Structure of matter and nature of chemical elements
- b. How chemical combinations take place
- c. The importance of the element carbon and the kinds of compounds formed from it
- d. Materials as a part of man's environment: dyes, plastics, and textile fibers, natural and synthetic

**D. Man in relation to the ideas that shape his actions****12. Nature of the universe*****Core ideas:***

- a. The universe consists of stars or suns of which there is a vast number, arranged in masses called galaxies, of which there is also a vast number, all with tremendous areas of empty space between.
- b. The earth and its moon belong to a family of planets circling around the sun, which is a moderate-sized star occupying an inconspicuous position within our galaxy.

***Subject matter:***

- a. Galaxies and stars
  - (1) The vastness of space
  - (2) Life cycle of stars
  - (3) Constellations
- b. The solar system
  - (1) Probable origin of the solar system
  - (2) Kinds of bodies which make up the solar system
- c. The earth
  - (1) Structure of the earth
  - (2) Weather and climate

**13. Evolution*****Core ideas:***

- a. Over long periods of time plants and animals, including man, have undergone changes due to natural selection of the best-adapted individuals to carry on the species in a changing environment.
- b. The major groups of humanity which are distinguishable on the basis of physical differences grade imperceptibly into one another in the regions where they meet.

***Subject matter:***

- a. Changes on the earth's surface: vulcanism, diastrophism, erosion cycle, climatic cycles
- b. Operation of natural selection and other factors in evolution
- c. Outline of the history of life on the earth
- d. Evolution of man
- e. Present-day races of man
- f. Evolution in nonorganic areas: human social forms, language, clothing, tools and machines

**14. Science and man's thinking*****Core ideas:***

- a. The scientific attitude can be applied to all types of human experiences and problems, while the scientific method is best applicable to data that can be measured or counted.
- b. It is important that each individual examine his beliefs in the light of pertinent scientific concepts, in order to determine whether these beliefs are consistent and satisfying.

*Subject matter:*

- a. Examples of applications of the scientific attitude and method
- b. Science areas which are related to religion

## METHODS OF TEACHING

Teaching methods used in the course differ somewhat in emphasis from year to year and from instructor to instructor. Consistently, however, all instructors use varied types of group experiences, such as discussions, demonstrations, field trips, lectures, and laboratory work.

The demonstration materials include motion pictures, both sound and silent, microprojections, charts, and models. Various types of demonstration dissections, microscopic demonstrations and experiments are utilized with appropriate units. Experimentation is being considered with recordings, both the commercial variety, such as are heard on radio science programs, and those made by teacher and students in the classroom.

Field trips, which are taken principally during the fall and spring quarters, are based on the idea that the local area may well serve as a laboratory for a study of the broad relationship of man to his environment. When students have participated in such a study in one community they will be better able to meet and understand problems in their home communities. The specific types of field trips which are used involve biological observations and collections, study of physiography and fossils, study of stars and other heavenly bodies, and studies of the local human scene and what it contains. This last type includes consideration of land usage, domestic animals and plants, food sources and processing, and local hospitals, weather bureau, radio station and science-related industries. Studies of vegetation types and land usage in relation to natural conditions are supplemented by photography and observations from the air, in which students are permitted to participate.

Individual laboratory work includes such experiences as observing microscopic pond organisms, dissecting standard laboratory forms, incubating hen's eggs for the study of live embryos, making models, testing out probability ratios in heredity, determining the composition of fabrics, experimenting with vegetable dyes, tanning animal skins, caring for laboratory animals, observing their reproduction and carrying out diet

experiments with them. Some of these are regularly done by class-sized groups, while others are used in connection with individual and small group projects.

A major portion of the work of the course consists of optional outside readings and projects. Although most project work is on an individual basis, students are always allowed to work in pairs or small groups if they can do so profitably. At the beginning of the year, experiences for class-sized groups are stressed and a minimum of project work is allowed. Later in the year, students who show an aptitude and a desire for additional project work are allowed to engage in it almost exclusively.

During the winter period when the weather limits opportunities for field study, the students in each class who are not doing project work primarily are permitted to select the group units which they will take up. Any of the prescribed units of the course that are not completed in this fashion are covered in required project work. All students must complete a minimum amount of acceptable work, either with a group or by projects, in each of the fourteen areas of the course.

In all types of course experiences emphasis is placed on use of the library, both from the standpoint of reference books and of current literature. The science librarian cooperates actively in the course, meeting with students in the classroom and for individual conferences.<sup>4</sup> Students are encouraged to read the science and medical sections of current newspapers and magazines, as well as semitechnical periodicals. The references used in connection with project work range from technical works usually considered beyond the level of the beginning student, to survey textbooks and popularized treatments of subjects of general interest, such as reproduction, heredity, and atomic power. In using technical books and periodicals students are taught to read for general ideas rather than details, and to "read around" technical terminology as far as possible.

#### IMPLICATIONS AND CONCLUSION

The work of the course as it is organized makes necessary a broadened concept of what laboratory work includes. Under

<sup>4</sup>B. L. Johnson, E. Lindstrom, and others, *The Librarian and the Teacher in General Education*, to be published by the American Library Association, 1948.

this concept any problem-solving situation which is real to the student becomes a laboratory experience, regardless of the materials and methods which are used. In a course based on student problems as this one is, nearly all the work becomes laboratory work in this sense.<sup>5</sup> The laboratory thus comes to include the use of books, motion pictures, recordings, interviews with authorities, field trips, and surveys, as well as more orthodox laboratory activities, such as experiments, dissections, and microscopic work. Projects, exploratory library reading, discussions, and even lectures, if participated in by the student in pursuit of a problem real to her, become laboratory experiences.

The scientific method is essentially a formalized problem-solving technique, and the scientific attitude is a natural out-growth of the necessity for correlating and evaluating data bearing on the solution of problems. Therefore the approach to the teaching of science which is used in this course furnishes a natural environment for the growth of these concepts. Furthermore, students who learn to put into practice the scientific method and attitude while seeking solutions to problems in the field of science that are real to them, are unlikely to forget these habits when dealing with other problems that are real to them outside the field of science.

Although this course has been developed at a junior college for women to fit a specific need and situation, a course built on the same general plan and basic philosophy could be constructed to fit any group of college youth who are not majoring in science, but who need a science course as a part of their general education. The problems brought up by young people of college age, and the questions asked by them, are always similar. They are concerned with the nature and the functions of man as an organism, his behavior, health, reproduction, and heredity, the universe as his home, and his relations with the world around him, including other people, other living organisms, the things that he uses, and the ideas that shape his actions. They are generally more biological than physical, although they draw upon all fields of science for the actual problems of the students who are taking it. It

<sup>5</sup>W. C. Van Deventer, "Individualized Instruction in a Basic Science Course," *Science Education*, XXX (December 1946).

should therefore always grow out of experience with a particular teaching situation, and be validated by research studies.

It is not necessary to make elaborate preparations for starting such a course. It may well begin with the work of a committee of students and faculty, listing problems that they believe ought to be included; then allowing all students as they work in the course to suggest additional problems. The thing most important is to free instructors and students from the necessity of thinking and working in traditional patterns. When this is done, real problems will show themselves, whatever procedure is used.

Studies of what is needed in the course can best proceed while it is in progress. Continued experimentation is necessary. It keeps the course dynamic and alive. Constant exchange of information and comparison of results among different instructors is valuable. One must always be open-minded about what to add, keep, or discard. There is no area in which the scientific attitude can be applied more readily than in the development of such a course. The instructor should keep the idea of student needs always paramount, experiment freely, watch results carefully, and let evolution do its work.

## The Single-Science Course at Princeton University

SCIENTISTS ARE imbued with an understanding of the spirit of research. The function of a science course for non-scientists is to infect the next generation of young men with that understanding, to introduce them to the Pilgrim's Progress of a research project. It is convenient for our discussion to consider that this process with our students takes place in three stages: (1) becoming curious, (2) learning facts, (3) exercising critical judgment.

All of us who are scientists have, in common, experienced these stages. First comes our own *curiosity*—dozens of questions flooding our minds, clamoring for answer. Once upon a time I became interested in the explosion of a mixture of hydrogen and oxygen gas. Why do they explode? How do the walls of the containing vessel effect the explosion? Why does increasing the pressure sometimes increase reaction, but sometimes decrease it? Why does packing the reaction vessel with glass wool prevent explosion? What is the influence of moisture? of temperature? of impurities? These and thousands of other questions flooded my mind clamoring for answer. To satisfy this curiosity I entered the second phase of my research project—*learning facts*. I read all that had been done and thought and said about the subject. I became a storehouse of specialized knowledge centering on this particular problem. I became an authority in this narrow field. I acquired the knowledge which made me competent to judge the work of others. Gradually I passed into the third phase—the *exercising of critical judgment*. I uncovered conflicting statements. I took issue with the conclusions of other experts. I challenged their theories, devised and carried out experiments to confirm or contradict their theories or my own. And

By Hubert N. Alyea, associate professor of chemistry, Princeton University.

then, in the end, I experienced the glowing reward which comes from original research, the joy of discovery.

All of us, as research scientists, have enjoyed similar experiences in our own research projects. Let us examine each of them in its proper sequence and consider how it should be presented in a science course for nonscientists.

#### AROUSING CURIOSITY

First, we must capture the intellectual interest of the student, arouse his curiosity to the point where he will want to spend far more hours on his science course than the catalogue prescribes. Not to charm or fascinate him, but to arouse his intellectual curiosity: this is the first objective. It is difficult, sometimes, for a scientist steeped in research as he is, to realize that the student is not necessarily enthusiastic about natural phenomena. More likely, being a nonscientist, he is not enthusiastic. More likely he has a keener appreciation than his science professor of the beauty of words, the harmony in music, or the loveliness of a painting; and he cannot understand why the scientist should appreciate the beauty of truth. This is what an artist says about us:

The scientists regard *truth* as the paramount issue . . . they crave a meticulous precision of observation, measurement, and statement quite alien to the other teachers of men. They exhibit an almost shocking insensibility to the cherished motives of belief. They do not ask whether what is sought is right or wrong, beautiful or ugly, useful or futile, comforting or distressing. They only ask whether what is found is an instance of something really happening.

Truth is the idol of science. By what device do we arouse this curiosity in the student? Primarily we must appeal to the familiar world about him: hormones, mesons, atom-smashers, the electron microscope, radioactive isotopes. This is the bridge between the student and the scientist. Questions about the air we breathe. What is fire? life? growth? These familiar topics should be used to capture the interest of the student.

One might argue that the general science course which covers a much broader field has an advantage in this phase. But chemistry is so full of a number of things, and the chemist himself so curious about life processes, the structure of the atom, the composition of the stars, and many other topics which extend to fields ordinarily considered beyond the field of

chemistry, I am sure that the chemist can sufficiently arouse the student's curiosity.

The same is true for any other single science. The physicist is interested not only in the laws of light, electricity, and magnetism and other purely physical problems; he, too, is interested in atomic structure, nuclear energy, physiology, and energy relations in biological reactions. He, as well as the chemist, can present an equally broad treatment of science. Moreover, one can be quite sure that a study of nuclear energy, for example, as presented by a physicist will be different from that presented by a chemist, but that it is equally unnecessary for the physicist and chemist to pool their approaches and give a joint course.

Curiosity can be aroused not only by selecting familiar topics, but by other valuable approaches and techniques applicable in any science. There is, of course, the historical approach—examining the rise and growth of chemical concepts—a growth which attracts us by the logical sequences in unfolding ideas. There are, too, the humanistic and social aspects of our science, and the methods of trial and error which are brought into focus by this historical approach. In addition there are the purely mechanical devices by which the curiosity of the student is stimulated: motion pictures (provided that they do not overshadow the personality of the lecturer), slides, exhibits, atomic and molecular models, or other visual aids. These techniques are part of any education and should be used frequently to stimulate the interest of the student. No, not merely to arouse passive curiosity, but catalytically to stimulate curiosity.

The intellectual curiosity in things about us is by far the most effective of all the techniques we should use in arousing the student. Our students are human beings. They are curious to discover how their science studies are related to their own experiences, to articles they are reading in current literature, to matters they are discussing in their dormitories. How do isotopes differ from the atoms of the ancients? How can a chemist establish the arrangements of atoms in the molecule of a hormone when the atoms cannot be seen? How does radioactivity reveal the structure of atoms? What makes the atomic bomb explode?

Yes, the student has a right to demand that the historical development be brought up-to-date. He wants something revealing, not a pickled and preserved specimen from the Middle Ages, and in our course Chemical Concepts which is given to nonscientists at Princeton, we discuss not only hydrogen in the Middle Ages, and Cavendish's subsequent discovery that water was a compound containing the element hydrogen, but we devote an entire week to tracing the radical changes which have occurred in our concepts of hydrogen during the past three decades: the atoms of hydrogen with their electrons in stationary states as conceived by Bohr and confirmed by spectroscopic studies of the Balmer series (1912); reactions with atomic hydrogen (1920-30); the prediction by quantum mechanics of the existence of orthohydrogen and parahydrogen molecules and their subsequent discovery in the laboratory (1929); the discovery of heavy hydrogen by Urey (1931), and the intense research with it, as in tracing the course of "heavy water" through the body; down to the interest in radioactive hydrogen today.

These are items which the intelligent student reads outside of the classroom. These are facts by which the lecturer can easily strike a responsive note in the student. This is the kind of chemistry which the student deserves to be taught. Why should we imagine him to be curious about the moldy, musty theories of the Middle Ages and then go out of the laboratory into a world of radioactive isotopes and atomic bombs?

But I hasten to add, with deliberate emphasis, that this treatment of the very new should in no way lower the intellectual level at which the material is being presented. Although its use enables us to capture the interest of the student, it is in no way intended to glamorize science. A student can become just as intellectually curious about transmutation and fission as about phlogiston and caloric. Why, therefore, present the unreal when the real, properly presented, can both fire his imagination and stimulate his thinking processes?

Curiosity is also aroused by extrapolating into the future. What concepts are still on shaky grounds? Which are likely to be changed within my generation? What new lines of scientific research will future chemists pursue? These thoughts help personalize science in the student's mind and assure

him that he is dealing with a living science not foreign to his own experience.

Laboratory work plays an important role in arousing curiosity. It makes the student feel that he himself is a part of the science which he is studying. He becomes "a doer of the word and not a hearer only"—no idle auditor of some beautiful exposition of scientific thought. Schedule 2 (page 138) illustrates typical laboratory experiments which the student can perform. Cookbookishness should be carefully avoided. The student should be encouraged to devise his own experiments no matter how amateurish, to record his own observations no matter how inaccurate they may be, to arrive at his own conclusions no matter how fallacious they are. The work must be his own.

If his observations and conclusions conflict with what he has been taught, so much the better; all the sooner he realizes the power of observation, the likelihood for error, the possibility of misconception and inaccuracies attending scientific research. Here is an opportunity to emphasize the importance of controlling all variables, of eliminating unnecessary errors, of extrapolating very little beyond the observed. If the laboratory experiments proceed smoothly with the intent of convincing the student of the niceties of science, the whole point of laboratory work is being missed. True, a few simple observations should be allowed to give the student confidence in himself, but I believe that the more irregularities in the exercise, the richer the experience for the student.

The laboratory work, then, arouses his enthusiasm by allowing him to feel that he is a scientific observer, that he is an active participant in science, not just an outsider listening to a lucid lecture about science. It is important, of course, to have the student himself make discoveries, no matter how trifling. He must devise new experiments and discover new facts in order to feel that he is not merely rediscovering those things which persons before him have done, or raising questions for which the teacher already has the answers. The laboratory exercises should be designed with this purpose clearly in mind.

#### LEARNING FACTS

Second, I have suggested that the student must learn facts. I believe, for instance, that it is absurd to conduct a course

in chemistry in which the student has not mastered the writing of chemical formulas and the balancing of chemical equations. The formula  $\text{Na}_2\text{CO}_3$  must mean a number of things to him: a chemical substance with definite chemical and physical properties; a particle containing two atoms of sodium, one atom of carbon, and three atoms of oxygen, certain fixed relative weights of these atoms; specific arrangement of these atoms or their ions in solid crystals; one molecular weight of this compound, and so forth. I realize that it is often the fashion to present balanced equations to the student and explain them in words. I think this is a great error. To be truly conversant with chemistry, the nonscientist should learn to talk the language. Concepts such as rate of reaction, equilibrium, mechanisms of reaction, the combining volumes of gases, and so on, are understood with considerably more confidence by that student who has learned to balance equations representing such reactions. If he is to be even slightly expert in the science, he must really learn the language.

It is on this second point, the learning of facts, that I think the single-science course has a decided advantage over the general science course. Several weeks are needed to make the student conversant with the language of chemistry. Obviously it is impossible to learn all of the languages of all of the other sciences in a short space of four semesters. No, we must restrict the field to a single science. More than that, in a course in chemistry we must further restrict the number of chemical concepts or case histories to a much narrower field than is covered in the orthodox chemistry course.

#### EXERCISING CRITICAL JUDGMENT

Finally, let us consider the exercising of critical judgment. This, of course, is the ultimate goal in a science course for nonscientists. The arousing of curiosity and the learning of facts are but means to this vastly more important end—*the exercising of critical judgment*—a discipline which the student will need the rest of his life. We must have learned from our scientific researches to guess intelligently; after all, to those who make the most intelligent scientific guesses we give Nobel Prizes. We want to encourage the student, in a like manner, to gain confidence in his own intellectual capabilities, so that he himself is willing to make intelligent guesses. In his later

life he will be counted upon time and again to make decisions, to make decisions with confidence, and to make them on a moment's notice. He will have gained practice in just this sort of thing in the science course which I am proposing.

#### SINGLE-SCIENCE OR GENERAL SCIENCE COURSE?

We have surveyed superficially three important stages in a research project and suggested that these are desiderata in a course in science for the nonscientist. Let us now examine whether these goals are best attained by a course in a single science or by a composite of several sciences. By single science I mean a course organized and presented by one member of only one of the sciences, probably in consultation with other of his scientific friends. The content of such a course may somewhat overlap a number of the sciences: a course which deals with the structure of matter may seem to contain a considerable amount of chemistry, physics, and biology; for instance, see the topics suggested in Schedule I (page 135). The chemist may well discuss heat, light, electricity, and the kinetic theory, all foster children of the field of physics; or he may consider the structure of a natural product, a foster child of biochemistry. But the chemist who is giving such a course is looking at these topics through his chemically tinted glasses; a physicist, on the other hand, might present these same topics, using an entirely different approach.

#### MATURITY OF APPROACH

My preference for the single-science course, rather than the general science course, lies in a realization of the intellectual depth which can be achieved by the single-science course. First of all, there is a *depth of curiosity*. We see it during the growing up of our children. They are all curious about the world into which they have just been born. The infant queries "what," the child asks "how" and "why," the adolescent inquires "may I." If the arousing of curiosity stops with the "what" stage or even extends to the "how" and "why" stages, it is shallow indeed. Only when the student's curiosity is stimulated to that depth where he himself wishes to participate, when he himself has the urge to exercise his own judgment and to criticize the theories and conclusions of others, only then has the curiosity reached an intellectual depth which I consider satisfactory.

This depth of curiosity finds its reflection in the depth of critical judgment which the student can exercise. The critical judgment itself is, as we have indicated, based upon the learning of facts. In a single-science course the student has time to learn the language of that science, and to learn it thoroughly. Because he is more conversant with the language, he is in a position to exercise judgment of greater maturity. This depth of critical judgment is very important. The student specializing in a single-science course is able to comprehend the technical aspects of that science far better than a person who has flitted butterfly-fashion from one science to another to sip the sweetness of this and that scientific flower. We do not want intellectual gymnastics in all of the sciences, but rather an understanding in a single science sufficiently mature to enable the student to exercise his own initiative, so that he is well informed and qualified to examine these scientific theories critically. Only intensive knowledge presages sound judgment.

A little knowledge is a dangerous thing  
Drink deep, taste not the Pcean spring.

This maturity of curiosity, and maturity in exercising critical judgment, can be illustrated by the accompanying Figure 1. In a single science, much time is spent in familiarizing the student with the language of that science. But once this is done, the student has considerable maturity in knowledge and ability to exercise mature judgment. In chemistry, for instance, as we consider one concept after another, illustrated by a series of case histories, the judgment of the student continues to grow until, even in the first-year science course, he may be considering advanced problems, and answering them with a maturity which, in its restricted field, may rival that of a graduate student. The corresponding progress in a general science course—for example, one term each of chemistry, physics, biology, and geology—is represented in the same figure. The student has barely learned the language of chemistry, mastered some of its principles, and commenced to think as a chemist, when the term ends and back he is again at the bottom of the chart learning all over again the language of physics. This discouraging cycle repeats itself for biology and geology. With such a scheme there is little opportunity to reach the maturity that concentration in a single science permits.

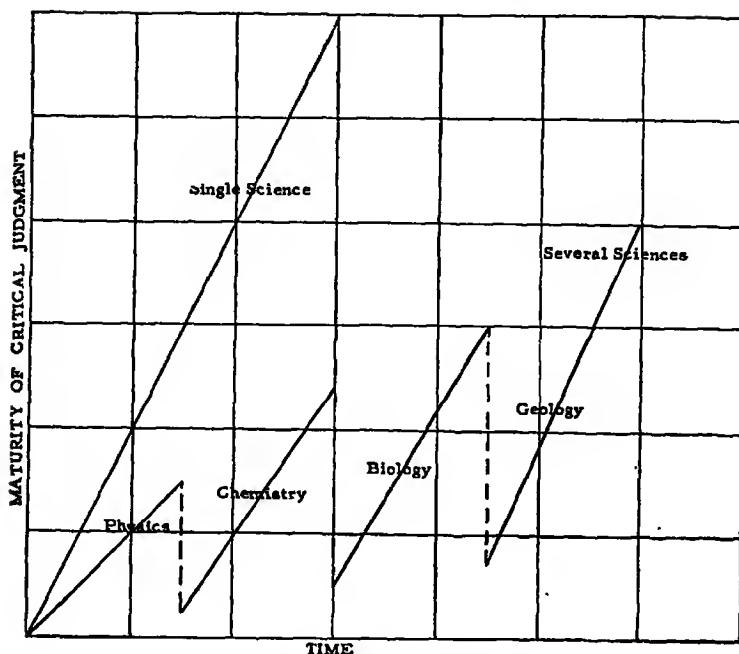


Figure 1. Maturity of Critical Judgment

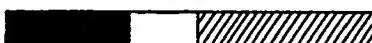
### SCIENCE FOR ALL STUDENTS

Although this paper is essentially concerned with science courses for the nonscientist, it might be well to indicate the differences of intent and content of the science course for nonscientists and for that student who will go on into a scientific career. In either course a balance must be struck between curiosity, the learning of facts, and the exercising of critical judgment. The time element is naturally the restrictive item. Assuming both courses are assigned an equal number of study and laboratory hours, the balance of the three factors will be considerably different in the two courses. Students electing a chemistry course for nonscientists have shown no inclination for science. Obviously then, their curiosity must be aroused. The facts in themselves are of little importance for the nonscientist; the only excuse for learning them is to prepare the student to exercise critical judgment. Only such facts as are indispensable, or contribute to the student's exercising mature critical judgment should be required in the course for

nonscientists. The exercising of critical judgment is paramount.

The course for scientists, on the other hand, will have quite a different balance of these three factors. Students electing it have already indicated their curiosity about natural phenomena. This item therefore becomes subordinate to the learning of facts. A factual scientific background as a base for advanced studies in chemistry becomes paramount in the beginning course for scientists. Subsequently, advanced science courses will afford him the opportunity of exercising critical judgment, of thinking on still higher levels. And so this third item, which is so important in the course for nonscientists, can be emphasized only insofar as time permits. See Figure 2.

For science students



For nonscience students



KEY:



arousing curiosity



learning facts



exercising critical judgment

Figure 2. Relative Emphasis in the General Science Course

The conflict between a single-science and a general science course resolves itself into a question of whether the learning of facts or the exercising of critical judgment is paramount. I am convinced that the latter is of vastly greater importance than the learning of facts, facts which will have been forgotten a few years after college, facts which could be acquired by leisure-hour reading in the years following college. The general science course looks toward both goals, attempting to give a broad coverage of facts in many scientific fields, and at the same time to encourage the exercise of mature critical judgment. Looking out upon both these objectives like the two-faced god Janus and hoping to reach both goals at the same time is, I am afraid, an achievement beyond the capacities of even the Princeton undergraduate.

#### THE DESIRED RESIDUUM

One may well inquire what will be the residuum from a science course for nonscientists. By examining this residuum

one can gauge the aims of the course, the likelihood of achieving these aims, and the value of the course. What will the student remember after he has graduated? As we think back to the courses we took in college and now consider valuable, we can sense that, though we did not know it at the time, they were making us grow in new directions. It is not merely that we learned new facts about the world in which we live, that we had a broader view of the interrelationships of the intellectual picture puzzle which we call life and the world, not merely that we were swept off our feet by a fascinating and glamourous scientific exposition. No, the most valuable portions of our education were those which stirred us intellectually, which made us grow beyond the subject matter of the course itself. In trying to meet the challenge which the teacher had put to us we were having intellectual growing-pains. These are the experiences which we all have in common as we look back upon certain courses with admiration and respect. A science course for nonscientists should furnish just such opportunities for individual intellectual growth. But, you will say, these are the aims of any course—in the humanities or social sciences, as well as in natural science. To which I would immediately assent. The value of such training in the sciences, and the advantages it offers over similar training in other fields of endeavor are the simplicity of factors, the limited number of variables, and the elementary nature of scientific reasoning. Science is therefore an admirable medium in which the student can exercise his critical judgment, can feel competent to disagree with and alter some scientific theories under discussion.

I am quite conscious that some scientists will claim that the science course for the nonscientist should also present a panorama of the world of science in which the human being lives, to make the student aware of the world of science of which he is a part, to emphasize the role of science in political and economic problems of the world, to help him understand the world of nature in which he lives. But interesting, indeed fascinating, as these all are, I do not believe that all of them combined can equal in importance the exercising of critical judgment, which to me seems to be the prime function of such a course. How well this is achieved depends almost entirely upon the teacher who is conducting the course. But if the paramount importance of critical judgment is clearly real-

ized, and consistently stressed throughout, such a course for nonscientists cannot help but be the better for it, no matter who is teaching it. The single-science course is better suited to this maturity of judgment.

#### SCIENCE COURSES FOR NONSCIENTISTS AT PRINCETON

According to the New Plan of Study initiated in the fall of 1947 at Princeton, each candidate for the A.B. degree must complete by the end of his sophomore year two one-term courses in each of four areas: (1) natural science, (2) social science, (3) arts and letters, (4) history, philosophy, and religion. At no point in the program of study is any one particular course required. The student is left free to choose between two or more courses.

Each of these so-called "distribution courses" is designed to contribute to the general education of the underclassman. In the first place, it presents content and method in perspective of all learning; it encourages the student not to lose himself in the internal logic of the subject, but to see significant relationships to other areas of learning. However, it is *in* a subject, not *about* a subject. It illustrates and applies the process of learning and evaluation as, for instance, by laboratory experimentation and evaluation of data. It covers a broad, not a narrow area. Finally it is planned by a group of teachers, but to insure integration it is presented under the responsible direction of a single teacher.

The distribution courses in the natural sciences available to the undergraduate are in the fields of biology, geology, chemistry, physics, and psychology. All include laboratory work.

#### *Schedule 1—a course in Chemical Concepts for nonscientists*

Seventeen years ago we initiated at Princeton a separate terminal course for nonscientists. Initially a survey of chemistry and its impact on civilization, the course changed more and more until by 1940 it sought to emphasize the methods of scientific investigation and the growth of scientific research. The present course is described in the catalogue as follows:

##### CHEMISTRY I AND II, CHEMICAL CONCEPTS

A study of the rise and development of our ideas in chemistry, especially of those experiments which have revealed (I) the composition of matter: of

atoms, molecules, ions, organic radicals, and the chemical elements; and (II) how the chemist has interpreted and learned to control chemical reactions. Laboratory work consists in devising and carrying out experiments, and evaluating data from them; it also includes a repetition of some classical researches in chemistry. Three lectures or class periods, and one (three-hour) laboratory period per week.

In practice the lecture section might comprise one hundred students, the class sections ten students each, the laboratory sections fifty students supervised by four instructors.

The purpose of the course is to present a process of thought by examining how great chemists, through the centuries, have (a) begun by eliminating so far as possible preconceived ideas, (b) planned and executed experiments in their search for relevant data, (c) thoroughly examined these new data, as well as previous evidence, weighing the evidence so that ultimately they (d) arrived at the logical conclusion, which confirms the original hypothesis, or (e) advanced newer hypotheses to fit the newer facts. This is a process of experimental thinking, a technique which the student can carry over into his later life.

By way of illustration, the contents of Chemistry I is outlined below.

#### WHAT IS MATTER?

The entire first term will seek to answer the problem: What is matter? It will show how science, down through the ages, has grappled with this question; how the concept of matter has changed as, with the development of newer research tools and new techniques, man has come ever closer to a clear understanding of the constitution of substances.

#### *Topic 1. The Language of Chemistry (4 weeks)*

This will be an introduction to chemical symbols, chemical equations, and the simple chemical and physical properties of the common substances air, water, and salt. This technical preface is necessary so that the subsequent lectures can be on a relatively advanced level.

- a. Rise of the scientific method
- b. Chemical language: elements, mixtures, compounds, symbols, writing of chemical equations
- c. Early, modern chemistry of air, water, salt
- d. Classification of the elements

#### *Topic 2. The Concept of Elements through the Centuries (1 week)*

- a. Ancients—alchemy
- b. Boyle, Priestley, Cavendish
- c. Discovering new elements 1774-1860
- d. Predicting new elements, Mendelejeef
- e. Identifying new elements, mass spectroscope
- f. Making new elements—transmutation, fission, 1919-46

*Topic 3. The Concept of Atoms and Molecules (8 weeks)*

An examination of the scientist's necessity for assuming the existence of atoms and molecules is followed by a discussion of atomic-molecular properties, all of which contribute overwhelmingly to the belief in the reality of such particles: their weight, number, size, shape, and structure.

## a. Evidence of the atomic-molecular nature of matter (1 week)

## (1) Atoms

Democritus, Lucretius

Radioactivity—Geiger and Marsden, Rutherford, Bohr

Dalton, Berzelius, constant proportions, multiple proportions

Mass spectrograph

## (2) Molecules

Gay-Lussac, combining volumes

Avogadro and Cannizarro

Contribution of organic chemistry

Electron microscope

## b. Weights of atoms and molecules (1½ weeks)

## (1) Atoms

From % composition;  $6.4 = \text{at. heat}; E_v = A$ 

Mass spectrograph

## (2) Molecules (their formulas)

22.4 liters . . . Gas laws, deviations from ideal gas

Van der Waals eq. of state . . . Victor Meyer method

Freezing point and other colligative properties

Ultracentrifuge, ultramicroscope

Diffusion data

## c. Numbers of atoms and molecules (1 week)

## (1) Avogadro's number

Oil film, Langmuir

Colloidal studies . . . Brownian movement, Perrin, etc.

Ultracentrifuge, Snedberg

From  $e/m$  and electrodeposition, Millikan's determination

## (2) The mole-weight relationships during reaction

## d. Size and shape of atoms and molecules (1 week)

## (1) Determination from Langmuir oil films, atomic vol. curves, x-ray data, compressibility, diffusion of gases and liquids

## (2) Crystallography, fibers, electron microscope

## (3) Studies with atomic models . . . stearic hindrance . . . rubber elasticity, detergents

## e. The structure of atoms and molecules (3½ weeks)

## (1) Atoms

General—Geiger-Rutherford experiments

Nuclear—isotopes, transmutations, fission

Planetary—spectrum, ionization

## (2) Molecules

Diatomie elements . . . allotropy  
Organic structure of alcohol, the benzene ring, a natural product  
Polymers—acetylene, benzene, giant molecules such as SiO<sub>2</sub> and silicones; carbohydrates; proteins  
Isomers . . . spatial . . . amines . . . optical isomerism

*Topic 4. The Concept of Ions (1 week)*

- a. The Arrhenius theory of ionization, modifications
- b. Ions in crystals
  - (1) Types of crystals
  - (2) X-ray studies of crystals

*Topic 5. Colloidal Behavior (1 week)*

Unusual properties attributable to particle size and not atomic or molecular constitution

*Schedule 2—laboratory work in Chemical Concepts course*

The laboratory work consists of ten projects of three weeks each which run through the two semesters. They include: preparation of a complex copper salt starting with cuprite ore from a local mine; separation of a dime into its components, silver and copper; measuring volumes of two gases combining with each other; determining atomic and molecular weights from specific heat, freezing and boiling point changes; measurement of the percentage of acetic acid in vinegar to determine its legality; a series of transformations of organic compounds, beginning with sugars and cellulose and transforming them successively through alcohol and acids to esters; cooling curves; measurements of rates of reaction; catalytic reactions and the influence of electricity, heat, and light in chemical reactions; qualitative analysis of cations (3 weeks only). Each project takes a total of nine hours. During the first three hours the student performs experiments which imitate certain classical discoveries which have been milestones in chemical history. Three different experiments are carried on simultaneously by different members of the class. After the experiments are done, at the end of the first three hours, the class meets for an hour and a half to discuss the experiments, their graphs based on their data, their sources of error, other ways of doing the experiments, and other experiments of a similar nature that might be done. The students themselves participate actively in the discussion. The remainder of this period and all

of the three-hour period of the succeeding week are spent in either repeating the original experiment or carrying out one of the other two subprojects which they have just heard discussed.

The three experiments which comprise the first project are given below to indicate the nature of the work:

#### PROJECT 1-A—CLASSIFICATION OF MINERALS

I want you to imagine that you are one of Aristotle's collaborators traveling about the world gathering specimens of rocks and classifying them. On your laboratory desk you will find thirty rocks, numbered but not otherwise identified. Examine them carefully and tabulate their properties (color, crystal shape, density, whether they scratch glass). After examining these rocks for one hour, we will proceed in a group to the mineral collection in the geology museum. You will see if you can identify the minerals from your own notes; and give name, location, and chemical formulas. For homework you will decide whether these minerals are ores and if so give production figures.

#### PROJECT 1-B—CHEMICAL TESTS ON ELEMENTS AND COMPOUNDS

I want you to imagine that you are Karl Wilhelm Scheele, the famous Swedish apothecary (1742-86). You have just received some packages of chemicals from your contemporaries Joseph Priestly, the Birmingham clergyman, and Antoine Laurent Lavoisier, master of the mint in Paris. They have heard of your skill in identifying a host of substances, and request that you examine these samples and report what they are.

From these observations you will find that some of the specimens sent you by Priestly resemble those forwarded by Lavoisier; indeed some of them even resemble substances you yourself have on hand. These findings you will report, together with your conclusions, to your fellow-scientists.

There are a number of tests you will probably make . . . etc. (Here follows a description of some tests the students may make.)

#### PROJECT 1-C—ALLOYS

The ancients were familiar with alloys for making coins, bronze (not brass) statues, etc. We shall make a tin-lead alloy, common solder. (Instructions follow for taking the melting point of lead filings heated in a crucible, and adding portions of tin until the eutectic is reached).

## The Sciences in Wisconsin's Program of Integrated Studies

**I**N THE FALL semester of 1948, the University of Wisconsin is offering, in the College of Letters and Science, a new sequence of studies to be called A Program of Integrated Liberal Studies. It is a two-year course to be offered at first to three hundred freshmen who will be expected to take the program in its entirety. It is a voluntary, alternate plan of studies, the completion of which will satisfy the general, non-departmental requirements of the College of Letters and Science. While it will be open to any freshman who wishes to apply, it is designed particularly for those intending to take the B.A. or B.S. degrees in the College of Letters and Science and for some intending to enter, at a later date, the School of Education, the School of Journalism, the School of Law, the School of Commerce, or the Library School.

### THE PROGRAM OF STUDIES

Two important principles underlie this program of integrated studies. The first is that since the goal of general education is preparation for life the courses can be broad rather than concentrated, and can be concerned chiefly with values rather than with techniques. The second principle is that through the exchange of ideas with other students who are studying the same courses at the same time, the average student can profit more from a prescribed course of study for his general education than from elective choices. He is still free to choose an era of specialization for the latter years of his college life and to select and prepare for a vocation.

By Robert C. Pooley, professor of English and chairman of the department of integrated liberal studies, Arch C. Gerlach, associate professor of geography, and Aaron J. Ihde, associate professor of chemistry, University of Wisconsin.

The studies of general education are recognized as falling into three large fields or areas. The *humanities* embrace such subjects as languages, literature, philosophy, religion, history, music, and the arts. The *sciences* are biology, chemistry, mathematics, physics, astronomy, geology, geography and their many subdivisions. The *social studies* include anthropology, economics, political science, and sociology. The integrated program provides a sequence of four courses in each of these three areas. These are new courses, planned to meet the particular need of drawing together the contributions of many subjects, and of relating them to each other to form a meaningful pattern.

The arrangement of courses is as follows:

**Humanities**

1. Classical Culture
2. Medieval and Renaissance Culture
3. Modern European Culture
4. American Culture

**Social Studies**

1. Early Man and His Society
2. Transition to Industrial Society
3. Modern Industrial Society, U. S. A.
4. The International Scene

**Science**

1. Introduction to the Physical Universe
2. Earth Science
3. Biology
4. Biology, continued

**Composition**

1. Theory and Practice of Writing
2. Nature and Functions of Language

Students completing the integrated program will have earned forty-seven credits in general education, plus some ten to thirteen additional in a language, in mathematics, or in any combination of elective courses. They will have satisfied the nondepartmental requirements of the College of Letters and Science and are qualified to continue in the college with a major in a specific department, or to transfer as juniors into the School of Commerce, the School of Education, or the School of Journalism. After an additional year in the College of Letters and Science they may transfer to the School of Law.

## PHYSICAL SCIENCE

### *First semester—The Physical Universe*

The first semester of the natural science program will be devoted to the physical universe, encompassing those areas of subject matter which normally fall within the fields of astronomy, physics, and chemistry. These subjects will not, however, be treated as separate entities. The borderlines between them are admittedly vague and no good purpose is served by retaining any distinction. Much will be gained by boldly discarding man-made barriers in order to integrate subject matter which logically fits together.

The course will not be designed to satisfy prerequisites for further work in science. Most students in this program will not become professional scientists. It is more important that they be given an appreciation for the relationships of science to their everyday life than that they be prepared to pursue successfully advanced courses in chemistry or physics. It is undoubtedly true that a few students will find the science courses in this curriculum sufficiently fascinating to pursue such work professionally. They will probably be required by their major department to take elementary courses in the field for reduced credit in order to fill in certain gaps not touched by the physical science course. The additional time required should not be regretted, for the student will be graduating from the university not only as a competent technician but as a man with a broad cultural experience as well.

The aims of the course in the physical universe are to gain: (1) familiarity with certain present-day concepts in physical science; (2) an appreciation of scientific methods as a way of dealing with problems; (3) an understanding of the impact of scientific developments on society; and (4) an appreciation of the readiness of the social order to accept and use scientific findings. We are living in an age where the influence of science on the lives of everyone is undeniable. Even the scientists themselves are coming to realize that a profound understanding of their specialty is not enough. It is equally important that the nonscientist have some understanding of the findings being made in scientific laboratories and the possible effects these findings may have on him and his society.

Students in the course will be representative of the fresh-

man class at Wisconsin. Some will have had extensive training in science and mathematics at good high schools. Many will enter with a meager background in these fields. The course, therefore, must be flexible enough in content to offer a good background in science to the latter group and at the same time offer a challenge to the former.

The course, listed for four credits, will consist of three lectures each week plus a discussion section of two hours. The program will be the responsibility of one member of the faculty and most of the lectures will be given by him, though others will be called upon for assistance in certain cases. The lectures will be supplemented by exhibits and experimental demonstrations. Visual aids, such as mechanical models, slides, and motion pictures, will be used whenever suitable materials are available.

The discussion sections will be composed of about twenty-five students. They will be conducted chiefly by graduate assistants selected for a broad interest in science and a sincere interest in teaching. The first hour of the discussion period will be devoted to general interpretation and clarification of the current subject matter by group participation. The second hour will be looked upon as a "laboratory" period. Laboratory work of the conventional type was deemed undesirable for this course and another kind of laboratory experience is yet to be developed. It has been felt desirable, however, to provide a scheduled time when students can work individually, but under supervision, on scientific materials. During some of these times the period will be devoted to supervised study and the solving of problems. At times it should be possible to supply chemical or physical material for experimentation. Other times will be used for "field trips" to university, state, municipal, and local industrial laboratories.

A textbook for this course has not been selected. A preliminary search has unearthed no available text which closely fits the intended aims and organization of this course. Probably one of the physical science survey texts now on the market will be selected and adapted to the needs of the students in this course. It is also felt that too great reliance upon one book is undesirable. Students will be expected to do a good deal of supplementary reading. They will go to original

sources when such are available in readable form. They will also consult reviews, biographies, and histories of science.

It is felt that any course which attempts, in a semester, to survey the fields represented here will offer only a hasty glance at a confusingly large number of phenomena. In order to avoid this fault, the course will be planned to sample in considerable detail some of the more important problems confronting physical scientists. Some areas which will be studied are:

1. The evolution of the heliocentric system of planets
2. Newton's law of universal gravitation
3. The rise of the modern concept of the elements
4. Classification of the elements
5. The laws of chemical combination
6. Development of our present-day concepts of atoms and their structure
7. The nature of electricity
8. The measurement of time
9. Light—as interpreted from undulatory and corpuscular points of view
10. Energy—its sources and transformations

Any of these areas offers excellent opportunities to bring out the gradual unfolding of scientific discoveries, the alternative hypotheses which are advanced to explain observed phenomena, the testing of hypotheses, and the revisions brought about through new observations. The effect of more refined tools (instruments) can be revealed. The effects of the introduction of quantitative measurements on scientific thought should likewise be explored. Above all, the significance of the problems to human society should be kept uppermost in mind.

The first area mentioned above provides an excellent opportunity to explore the various ideas which have been advanced to explain the behavior of the wandering stars, or planets. The basis for geocentric explanations can be considered, leading to the introduction of epicycles to allow for backward planetary motion in a system of circular forward motion. The heliocentric system suggests itself as an alternative hypothesis. Studies of observational data naturally follow so as to bring about a choice between the two systems. The astronomical thought of the Greeks and of Copernicus, Brahé, Kepler, and Galileo will naturally receive extensive consideration. The reception of the Copernican system by seventeenth century Europe develops as a part of this picture and provides opportunity to consider the relation between the

state of social thought and the acceptability of scientific developments.

This area of investigation leads logically to Newton's law of gravitation which later served as the basis for the predicted existence of the planets Neptune and Pluto before these planets were actually observed.

Other problems of physical science can be developed in similar fashion. At the same time there will be a concerted effort to correlate the study of science with the social studies and humanities portions of the curriculum.

#### *Second semester—Earth Science*

The Earth Science course is designed to be of general educational value rather than to serve as an introduction to departmental specialization in either geography or geology. The fundamental objectives of the course are: (1) to give students a better understanding of the climatic phenomena, earth materials and processes, land forms, and natural resources which constitute the physical earth as the home of man; (2) to stimulate thinking about cause and effect relationships in the physical realm; and (3) to increase critical observation of landscape features and rational interpretation of their origin, interrelationships and significance to man.

Students also will gain an incidental but useful acquaintance with such basic tools of the earth sciences as globes, atlases, weather maps, topographic maps and models, air photos, and stereoscopes.

The course is organized on the basis of two lectures and a two-hour discussion-laboratory period each week for three semester credits. Slides, maps, models, and educational motion pictures are used to illustrate and supplement lectures. Laboratory time is divided between discussion and demonstration of basic principles and supervised work on laboratory problems concerning types of climate, rocks and minerals, land forms, and natural resources. The local field trips and one all-day trip are scheduled to supplement laboratory work with field observations. A critical review of available texts in the earth science field reveals none which is ideal for the purposes of this course. The standard physical geography and geology texts stress either form or process, or distribution, or human use instead of fully integrating all of those factors, and the

textbooks prepared specifically for earth science courses include too little subject content. Regardless of the textbook adopted, supplementary readings should be assigned to give students a thorough introduction to the following standard texts:

V. C. Finch and G. T. Trewhatha, *Physical Elements of Geography*, McGraw-Hill, second edition, 1942

C. R. Longwell, A. Knopf, and R. E. Flint, *Outlines of Physical Geology*, John Wiley and Sons, second edition, 1941

L. Martin, *The Physical Geography of Wisconsin*, Wisconsin Geological and Natural History Survey, Bulletin 36

H. D. Thompson, *Fundamentals of Earth Science*, D. Appleton-Century Co., Inc., 1947

The subject content of the Earth Science course will encompass the following general fields of information:

1. An analysis of the elements and controls of weather and climate, and the distribution of climatic types over the earth
2. The gradational processes and resultant earth materials and surface features
3. The tectonic processes of volcanism and diastrophism and resultant earth materials and land forms
4. The origin, distribution, and human use of natural resources such as soils, water, minerals, and natural vegetation

The sequence of subject-matter presentation results largely from the position of the Earth Science course in the integrated liberal studies curriculum. Since a four-credit course on the Physical Universe precedes the Earth Science course, students will have gained some previous acquaintance with the fundamental principles of physics, chemistry, and astronomy. Transition to earth science study is consequently made through a study of the atmosphere and its behavior in accordance with those basic principles, and of the earth's planetary behavior in relation to seasons.

The weathering of rocks and the creation of land forms and sedimentary deposits by gradation follow in logical sequence. The remaining rocks and minerals and land forms result from earth processes (diastrophism and volcanism), but are usually altered by the effects of climate or the work of erosion, so they lead from those previously treated topics into the analysis of natural resources such as minerals, soils, water, and vegetation. Students then undertake a study of the biological sciences the following semester.

Since the treatment of any given topic in the Earth Science course immediately involves several related topics, some of which have not been previously introduced, the integration of subject matter into meaningful patterns and logical interrelationships requires the establishment of some common denominator. That common denominator is the basic theme that all the physical phenomena, earth materials and processes, land forms, and natural resources derive their real significance from their function in making the earth the home of man. For example, climate affects weathering and erosion, soil types, natural vegetation, drainage, and the location of certain commercial mineral deposits, but one might also begin with any one of those factors and find that all the others are just as much interrelated as if the discussion began with climate.

Consequently, the Earth Science course follows a sequence of major topics which seems to fit logically into the integrated liberal studies curriculum, and presents a series of progressively complex, interrelated problems. For example, one might take the problem of mountains. How did a given mountain range originate? What physical processes have been involved in its formation? Was it always there? How has it been changed from its original form? How has it been affected by climate? What influence has it exerted upon the climate of that area? What natural resources would normally be associated with that type of mountain range in that climatic region?

The answers to these and other related questions may be found chiefly through a study of earth processes and materials, but their meaningful interpretation can best be accomplished by viewing the closely interwoven patterns of the physical environment as a background for man's economic, political, and social activities, thus bridging a gap between the physical sciences and social studies.

#### BIOLOGICAL SCIENCE

This course is as yet undeveloped, but in goals it will follow the principles enunciated for the course in physical science. The materials of the course will be drawn from the subject matters of botany, zoology, genetics, and psychology, but the subjects, as in physical science, will be utilized in such a manner as to develop their interrelationships and their significance to the individual student and to the society in which he will live.

Some topics suggested for rather thorough exploration are:

1. The characteristics common to living organisms
2. Food and digestion
3. Sex and reproduction
4. Heredity
5. Evolution
6. Competition and cooperation

The course will consist of two semesters, with three credits in the first semester and four in the second. Instruction will be by lectures and lecture-demonstrations, with a two-hour weekly discussion and laboratory period. The laboratory work will include observations, motion pictures, field trips, and a fair amount of work with the microscope.

## **Science in General Education at the University of Iowa**

**T**HE PROGRAM of general education launched at the University of Iowa in 1944 had as its purpose the broad, liberal education of the individual. In the language of the statement which the faculty adopted in establishing the program: "The primary function of the College of Liberal Arts is to provide a liberal education, that is, to encourage the student in the fullest possible development of his capacities as a person and as a member of society. The fundamental goal is the well-rounded development of the individual—intellectual, spiritual, physical, emotional, and aesthetic."

To achieve these objectives the faculty adopted a program of general education including studies in the various fields of knowledge. Each student is required to complete a one-year, eight-semester-hour course in each of the following four areas: (1) natural science, (2) social science, (3) literature, and (4) historical and cultural studies.

In the natural sciences, one course is required from among the following three: Biology of Man, Earth Science, and Introduction to Physical Science.

In the social sciences, the student may choose one of three courses: Introduction to Social Science, involving a knowledge of economic, social, and political features of modern life; Government, a study of government as a universal phenomenon of human society; and Man and Society, which considers the common denominator of the social science disciplines.

In the area of literature, the student must elect two of the following: The Western Tradition, which includes selections from Greek literature in translation and from the King James

By Walter F. Loehwing, head of the department of botany, A. C. Trowbridge, head of the department of geology, George Glockler, head of the department of chemistry, and G. W. Stewart, professor of physics, State University of Iowa.

Bible; English and American Literature; Introduction to Modern Literature.

The options in the historical and cultural studies, from which the student must select one, are: Western Civilization in Modern Times, a course dealing with the unfolding of Western civilization from the end of the Middle Ages to the present; Introduction to the History of Ideas, an introduction to the world of contemporary thought by a study of some key ideas from the fields of ethics and from the social, physical, and biological sciences and philosophy; Introduction to Religion, a brief summary of the religions of the world today; History and Appreciation of Art, History and Appreciation of Music, and History and Appreciation of the Theater, three separate one-year courses.

In addition to the core requirements the student must show his competence in communication skills, mathematics skills, physical education skills, and foreign language by passing an examination or by taking appropriate instruction in these fields, which in most cases is an eight-hour course covering one academic year.

The three interdepartmental courses in the natural sciences, primarily for students not intending to major in science, will be described by the staff members in charge.

#### BIOLOGY OF MAN

The core course, Biology of Man, deals with the basic values of biology in relation to civilization and modern culture. It endeavors to develop the fundamental principles of biology and the actual use of the objective techniques of science. The scientific method of thought and experimentation is employed in a critical manner, designed to indicate both its validity and present limitations. Opportunity is provided for development, presentation, and interpretation of biological data. In harmony with the objectives of general education as developed at Iowa, this course aims to provide a stimulus to the student to learn by employing active student participation in laboratory and discussion sessions.

This is a full-year course carrying eight semester hours of credit, and is taught at the freshman-sophomore level primarily for students not intending to specialize in science. It is interdepartmental in character, two lectures a week being

given to the entire class by senior staff members of four participating departments. Two-hour laboratory sections limited to twenty-four students each meet once a week, followed by a one-hour discussion-quiz period under instructors broadly trained in biology. For purposes of integration of the course as a whole and to secure uniformity of instruction among the numerous laboratory and discussion sections, the staff audit the lectures. Regular weekly staff meetings provide opportunity to preview laboratory exercises, to integrate and criticize instruction, and to handle routine matters such as distribution of materials, grading, attendance, and planning of discussion topics. No single textbook has been adopted, but sufficient library copies of a wide variety of the best biological texts have been made available and appropriate assignments are made from these. Mimeographed lecture notes serve to integrate the assignments as well as to outline the organization of the entire course for the student.

Motion pictures and lantern slides are employed during lectures. In addition to individual work by the student, liberal use is made in the laboratory of demonstrations and visual aids such as models, charts, living and preserved specimens, and commercial products. Several examinations of an objective type are given during the year, largely comprising judgment rather than pure recall questions. Drop quizzes are used on occasion in lectures and discussion sections.

### *Organization and content*

The following tabulation presents the organization of the course as conducted by the staff of sixteen members, nine of whom are of professorial rank.

<i>Unit</i>	<i>Time</i>	<i>Lecturer</i>
1. Evolution of Man	2 weeks	Geologist
2. Human Anatomy	5 weeks	Zoologist
3. Human Physiology	4 weeks	Zoologist
4. Nutrition	5 weeks	Home Economist
5. Plant Kingdom	4 weeks	Botanist
6. Conservation:		
a. Soil and Plants	2 weeks	Botanist
b. Water and Wildlife	3 weeks	Zoologist
7. Heredity	2 weeks	Botanist
8. Hygiene	5 weeks	Zoologist

The following topics comprise the major content of the first semester of the course which deals primarily with man as an

organism: fossils and their interpretation; early man and his evolutionary progress; the anatomy and physiology of skeleton, muscle, skin, circulatory and reproductive systems; the role of minerals, carbohydrates, fats, proteins, and vitamins in human nutrition, food habits, man's dietary, and sound regimens. The semester stresses man in relation to his environment and comprises units on plants in relation to man with major attention to thallophytes and spermatophytes; conservation of renewable natural resources with attention to soil, crops, timber, streams, and wildlife; personal and public hygiene and heredity.

The major problems in the teaching of an interdepartmental course have been the selection of content consistent with the aims of general education, incorporation of a wide range of important biological concepts, and their integration to provide a logical progression of ideas for a full-year course in biology. A workable solution of this problem has, however, been found. There is also need for a single suitable text which has been met temporarily by a fairly comprehensive outline of lectures and laboratory exercises.

In the early years of the course, the number of participating departments was somewhat larger, in an attempt to provide a very broad overview of biology, and more stress was given to functional and social aspects of biology. As enrollments in the course increased, it became difficult to obtain section instructors who were broadly enough trained to teach with competence the wide range of subject matter covered during the entire year. It also proved difficult to merge instructionally the highly objective viewpoints of biological science with the subjective aspects of biology of interest in social science. Though some breadth of subject matter was sacrificed by restriction to four departments, the course gained in improved understanding of scientific objectivity by students, facility of organization, quality of instruction, and economy of operation.

In common with other core courses at Iowa, Biology of Man was organized on a terminal basis. Many students have, however, chosen to continue in additional elective courses in biology. This response has raised questions as to the best manner of providing for such students in regular elementary courses of the participating departments. Thus far it has been possible to

make appropriate and desirable adjustments on an individual basis.

Though the course has been primarily designed for presentation of biological principles, the highly egocentric and pragmatic interests of many students as well as the aims of general education have led to inclusion of practical applications where content has been adequately developed.

### *Interrelation*

As one attempts to evaluate the major contributions of the biology course to the general education program at Iowa, it would seem that this course presents a broader overview of biology as it relates to man than is obtainable in a single elementary course of the participating departments. The wide range of biological concepts and methodology as these apply in several different biological disciplines seems to offer distinct advantages to the nonscience majors who constitute the bulk of the enrollment in the course. It may be noted that the lecturers are not only mature scholars of high repute in their respective specialties but experienced teachers with a lively personal interest in the objectives of the course and in general education. Many of the section instructors are also of professorial rank and possess excellent reputations as teachers and biologists. All participating instructors are members of departmental staffs and most of them are engaged in research and in the teaching of other courses. Thus in addition to long experience, senior staff members contribute a diversity of talent to the course.

Over a period of years excellent teamwork has evolved quite naturally among the large staff of the course. Criticism in staff meetings is constructive, frank, well received, and characterized by a spirit of mutual helpfulness. One of the unique features has been the presence of the staff at lectures. Comparison of the various lecturers by students and staff is, of course, inescapable and has served to provide a wholesome stimulus to good teaching. No lecturer has cared to run the risk of casual teaching in the presence of his professional peers in the audience. Impressions of the lectures are freely conveyed to the speaker by the auditing staff and have proven quite helpful. Development of this feature has been natural and quite spontaneous. It has been an important factor in maintaining

good teaching standards and integration of subject matter. In recognition of staff devotion to the interests of this course, the university has reduced other responsibilities and made upward adjustment of stipends.

As one reviews the project as a whole over a period of years, the biology course has largely eliminated the usual lines of cleavage between departments and there has developed a reasonably integrated body of biological content of a scope suited to the general education of undergraduates not primarily interested in science. Unity of content has been striven for on the basis of similarity of principles and concepts rather than along the usual departmental lines. The course is not of a survey type as it retains the orthodox features of regular science courses, including laboratory. Technicalities have, however, been eliminated in favor of major principles. Though enrollment in the course was doubled at the beginning of the current year, student demand for it is still in excess of facilities and staff. In view of this fact and as an evaluation of standards, questions taken from examinations prepared for similar courses at other institutions have been administered at Iowa with very acceptable achievement. The course, in brief, seems to provide a workable method of attaining the educational objectives for which it was organized.

#### EARTH SCIENCE (Geology and Astronomy)

This course is designed primarily for students in general education who when they register do not intend to take more than the minimum requirement in the sciences. A small number (2 percent at present) know in advance that they wish to specialize in geology and take Earth Science as an introductory course in this subject. Another small number (less than 2 percent this year) develop an interest during the first semester and declare a major in geology at the beginning of the second semester. A few others may take additional courses in geology or astronomy or in other sciences and may even become professional scientists. Thus, for about 96 percent of the class this is a terminal course.

#### *Objectives*

The general idea is to permit, encourage, or even require the student to secure educational values largely through his

own efforts, rather than to hand out to him predigested facts or even ideas.

The first major objective is to help the student secure at least some understanding of the earth on which he lives. Indeed, by recognizing the biosphere as a grand division of the earth along with the lithosphere, atmosphere, and hydrosphere, mankind becomes actually a part of the earth. If a cultured person is one who understands his environment and what goes on around him, then a study of earth science is cultural.

Another important purpose of the course is to cause the student to learn to think. As we see it this can be accomplished only by the student doing considerable thinking for himself.

Another objective is to develop in the student the ability to solve scientific problems, and for that matter the everyday personal problems of life, by the use of what has come to be called the scientific method. The whole course illustrates the scientific approach and certain lectures, recitations, and laboratory exercises specifically bear upon this subject.

Other purposes include imparting information for its own sake, enriching the lives of students by a better understanding of nature, making better travelers of them, and presenting the principles involved in the development, uses, and conservation of natural resources of the earth.

#### *Content and organization*

Main topics included are: geomorphology, or land forms and the agents, forces, and processes by which they are developed, including wind and deserts, ground,-stream,- and lake-water and water supplies, glaciers, surf and the development of shorelines, volcanoes, earthquakes; the development of soils from other earth materials and the general classification of soils; the elements of the science of weather and climate as apposed to "weather superstition"; introductory oceanography; elementary cartography; scientific hypotheses of earth origin and a general outline of earth history; economic products including the origin, distribution, production, and industrial and political aspects of metallic ores, nonmetallic products, and liquid, gaseous, and solid fuels.

All these subjects are definitely related to human affairs, and their geographic effects on society are stressed.

The course is thoroughly organized and integrated. Each topic leads logically to the next one. Each laboratory exercise

definitely supplements some preceding assignment and/or lecture. No student gets credit for taking any part of the course without taking all of it and none is permitted to take the two semesters in reverse order. Monthly schedules giving all assignments, lecture and recitation subjects, laboratory exercises, and examinations are mimeographed and handed to the students as a working program. Weekly staff meetings of recitation and laboratory instructors serve to standardize the instruction, but oral discussion is not limited in any way.

Each week there are two one-hour lectures, one two-hour laboratory period, and one one-hour recitation. Classes consist of twenty-five to thirty-five students.

For most of the lectures there are definite outside textbook assignments. This year the lectures, in two sections, are divided unequally among four professors and one assistant professor of geology, one professor of astronomy, and one instructor of geography.

In the laboratory, students work individually on minerals, rocks, ores, fossils, diagrams, sections, and topographic, geologic, and weather maps, in sections of twenty to twenty-eight students each, under graduate student assistants. From the laboratory outlines all special techniques and skill have been eliminated and also almost all purely quantitative determinations. We are firmly convinced that, in Earth Science at least, laboratory work is essential. There should be opportunity for each student to labor in his own way and at his own gait but with some staff member present to keep him working and to give advice and help as needed.

The chief purpose of the recitations is to permit each student to express himself orally, to discuss subject matter with other students and an instructor, and to raise any question at all that might be suggested by the course. The recitations consist of oral reviews and discussions of preceding assignments and lectures and are conducted by the lecturers or part-time instructors.

Final and "within the semester" examinations are of the objective type. Lecture quizzes and laboratory exercises require the writing of numerous short essays.

#### *Difficulties and weaknesses*

There appear to be at least two inherent major difficulties in courses of this sort and they are related.

Adequate textbooks for this particular course in Earth Science are wholly lacking. In the first semester Worcester's *Geomorphology* and a part of *Elements of Physical Geography* by Finch and Trewartha are used. Students are required to buy Worcester and to use it not only for outside assignment, lectures, and recitations, but also to have it in the laboratory. About a hundred copies of Finch and Trewartha are on reserve in the library during the study of weather and climate. In the second semester *Outlines of Historical Geology* by Schuchert and Dunbar is required, but this little book contains little or no material on a good many of the subjects studied, especially on economic resources.

The only apparent solution to this problem is the writing of a textbook for this particular course by one or more of the course staff. This the staff has neither the time nor the special interest or ability to do. So far at least it has not been possible to prepare and print a syllabus. Laboratory outlines designed especially for this course are mimeographed and handed to the students free of charge or printed and sold through regular commercial channels.

An even more difficult problem is in securing, training, and retaining an adequate staff of lecturers, discussion leaders, and laboratory conductors. Ideally the whole staff should be made up of productive scholars who are actively doing research, who teach more advanced courses in geology or astronomy, and have enthusiasm for and ability in this sort of teaching. But many research men make very poor teachers at this level even if they have the interest and ability. It is next to impossible for one to contribute effectively to the course in Earth Science, to keep up in his special field, and to do research. Participation in this course notably reduces productivity. The most useful member of the Earth Science staff is an ex-junior college teacher who teaches otherwise only one two-hour course in geology and does little or no research. The course simply could not operate without him. At least one more person of the same type is badly needed. If all lecturers and recitation leaders were doing research and departmental teaching, and Earth Science were properly taught, the geological staff would have to be doubled or trebled. Even then it is doubtful if there are half enough good general education teachers.

It is obvious that the recitation classes are too large. For each student to talk about a minute a week is not enough. More than one recitation a week or division into classes of ten or less is highly desirable. Again there are just not enough mature teachers prepared to handle wisely any question that may arise.

This course is supposed to include both geology and astronomy, but only enough astronomy is included to support weather science and hypotheses of earth origin. Astronomical staff to organize, equip, and conduct laboratories and to lead discussion groups is simply not available.

### *Summary*

In spite of difficulties and shortcomings some of the major objectives are believed to be reached fairly well. The average student secures a large amount of generally useful information and by learning the story of earth history and acquiring a picture of the earth and of earth processes and of earth resources becomes a better adapted and cultured person and perhaps more appreciative of scenic features and other natural phenomena. The scientific method should be clear to him and he might even use it in a practical way on occasion. It cannot be claimed, however, that the average student improves much in creative thinking.

## INTRODUCTION TO PHYSICAL SCIENCE

(Physics and Chemistry)

The fundamental concept of general education on which this course is based is the following proposition: An educated person should have some acquaintance with the physical world in which he lives, from various points of view. Introduction to Physical Science is also a full-year course, with eight semester hours of credit; physics is studied the first semester and chemistry the second.

### *Physics*

At the outset it was quite obvious that four semester hours could not possibly be adequate for the mastery of any portion of that body of knowledge termed physics. Neither could a survey of the subject suit the purposes of general education. The objectives stressed and the reasons for doing so will appear as the description of the course proceeds. There is an

automatic integration of the physics and the chemistry which follows since the principles taught in the former, especially atomic structure, are used in the latter.

The difficulty of selecting a textbook in such a physics course rests in the fact that college texts are full of formulas, and problems requiring computations from formulas. If such books were used the student would probably have adopted an attitude of futility. On the other hand, a book that could be read with understanding by those with no high school science or mathematics would also have been inadequate. Hence a compromise was reached by adopting a book which could be understood but which would nevertheless supply adequate descriptive material. This text was supplemented by a list of more than seven hundred questions, plus another hundred memory questions on nuclear physics. From both of these daily assignments were made. The questions and their answers became the core of the course; they compromised what is ordinarily called the "textbook." The descriptive book, Luhr's *Physics Tells Why*, touches upon the usual general subjects of physics, including atomic energy, is highly selective in its material, and is not a survey. Its content is conspicuously related to daily life.

The only lectures consist of experimental demonstrations. Almost unavoidably the "lecturer" or classroom instructor refers here and there to applications, or clarifies points already studied, but lecturing to extend knowledge of subject matter or for entertainment is avoided. Instruction is given in groups of one hundred. Because of the nature of the subject, a further division into discussion groups seems not to promise better results. It seems preferable to emphasize the student's own responsibility in acquiring an understanding.

*Three special objectives.* Of course factual knowledge is acquired through the daily assignments, but this knowledge is definitely increased by pursuing three other goals which are especially emphasized. The first is the applicability of physical principles to the common life about us. This is accomplished by the descriptive text and by the bearing of the questions regularly assigned. The second is the opportunity to think independently and to cultivate confidence in the ability to do so. The third, an extension of the second, is to give the student an awareness of the possibility of his *creativity*.

*at his own level of attainment.* The last two will be discussed at greater length. The three goals specifically mentioned are certainly not all the teacher has in mind, but they are the ones which receive the most attention. Again it should be said that the attainment of these three special goals does not reduce the acquisition of factual knowledge but indeed adds to that knowledge a better understanding.

*Independent thinking.* It is difficult to achieve the goal of independent thinking. The method so far tried in this course may be described as follows: the answers to the assigned questions are not found in the reference book and cannot conveniently be located in the library; the student finds that he must think them out for himself. Even his fellow students cannot be trusted to give him the answers that are clearly and fully correct, for these answers are not numerical but descriptive. Certainly many of these questions can be answered merely by recalling factual material, but the effort is made to have as many as possible "thought" questions, demanding independent reasoning. In the classroom the answers to the assigned questions are discussed at a speed which requires previous study and effort. And the understanding of these questions is made of basic importance. With the exception of a few questions on Luhr and on lecture experiments, all the nine one-hour tests of the semester are based upon these questions. In these tests it is assumed that to "understand" implies an ability "to use, to apply." Hence, these tests are composed of questions like those in the original set, but sufficiently altered to require the student to apply the principle involved in a way enough different to insure that mere memory will not provide the answers. Such questions are difficult and the passing mark used must be lowered accordingly.

In order to keep up daily work and to give the student a good estimate of what is expected, daily ten-minute quizzes are provided, covering both questions of the previous day and the current assignment. This method of instruction favors the essay type of question.

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*Conscious experience in creativeness.* This goal can be brought to the fore by a determined effort, particularly if the instructor is one who has himself struggled in a serious creative effort in his graduate study and later in his professional life. At the present time, the instructor, to assist in attaining this goal, gives several "contest" tests. These are new and difficult thought problems. Proposal for such a contest test is preceded by a series of short, carefully worded discussions, pointing out the advantage of such a trial of one's ability to think through a difficult problem. The nature of creativeness in scientific thinking is explained as best it can be and stress is laid upon the fact that one's *general* abilities, applicable elsewhere, are largely responsible for success.<sup>1</sup> In discussing the results of these contest tests, emphasis is laid upon the possibility of cultivating an habitual attitude of creativeness. The instructor insists upon pointing out successes in creativeness in these tests, for the awareness of the student is all-important if any transfer of such a habit is cultivated.<sup>2</sup>

This effort on the part of the instructor requires great care and ample faith. It is a difficult venture.

*Evidence of the attainment of special objectives.* In the use of special methods the teacher should seek to measure the effect of each one. In general, if one cannot obtain the necessary data with reference to a specific method, he should be able at least to point out devices and processes in instruction which must leave definite impressions. There is no way in the physics course to establish that the student has actually improved in independent thinking in all his studies or that the general creative attitude has become habitual to a small degree. Yet the "transfer" or the wide use of the general abilities is a definite objective. Nevertheless, by means of a poll of a limited number of students in each class-standing group, A, B, and C, a serious evaluation by the students of the

<sup>1</sup>Reference is not made here to what has become commonly termed "the scientific method," for the methods are many even in an experimental science. This course does not discuss methods of acquiring data or of dealing with them after they are in hand. Its emphasis is rather upon the initiation of inquiry, the finding of the key difficulties, and the application of the correct principles. This aspect is often overlooked in the anxiety to teach "scientific method," but it is one of the most important. Every course in general education has its own contributions to make to thinking, and thus to the so-called "scientific method."

<sup>2</sup>For a detailed discussion of creativeness at one's own level of attainments, see G. W. Stewart, "General Education and Student Experience in Creativeness," *Journal of General Education*, II (October 1947), 41-44.

various methods was made—not how well these methods were "liked," but how they should be rated for educational value in the student's own concept of liberal education. The uniformity of response shows that the highest value is placed upon independent thinking and the application of principles in everyday life. Some students have volunteered the comment that they do notice changes in their attitude in other courses. At any rate, the instructor is definitely encouraged to refine these special methods. He is not suggesting a *like* stressing of these methods in any other subject matter than physics. Rather, he sees clearly that physics affords an excellent opportunity to emphasize the objectives chosen.

*Future improvements.* If the length of the course, four semester hours, remains, doubtless an effort will be made further to improve present methods and to continue the omission of the laboratory. In keeping with the spirit of the course, any laboratory study would need to be specifically tailored, and this development should probably await further curriculum changes or it should be attempted first with a small group. That the course can be materially improved is quite evident. It should be made to present an *attractive challenge* with a *conscious thrill of achievement* as a reward. Recreational athletic games of this sort are successful. The art of teaching this kind of a course in physics should be developed until it meets with a corresponding success. For example, we have not yet found the most effective use of lecture experiments in cultivating the habit of independent thinking; neither have we learned the best ways to make such thinking a pleasure.

The course as described is now in its third year. The active interest of a second member of the staff, who now teaches a section of his own, seems to be a good way to improve the quality of the instruction and to give such an elementary course required importance in the work of the department of physics. This sharing of interest gives a valuable experience in teaching to a younger member of the staff, improves the quality of instruction, and gives this elementary course greater departmental interest.

### *Chemistry*

The course in chemistry is designed to give the students knowledge about the physical world as the chemist sees it.

The students, of course, are neither majors nor minors in chemistry. The intention is to tell the oncoming generation *about* chemistry. It is not expected that they will need the knowledge presented in their future vocations. The course is meant only to broaden the horizon of the students and help them to understand the civilization in which they will live. The program is not planned for persons expecting to make chemistry their profession or even for other science majors or engineering, pre dental, and premedical students. It might be said to give a limited "overview" of the field. Naturally, a choice must be made even there, because it is not possible to cover the whole science of chemistry in thirty-six lectures. Moreover, it is not necessary. It is possible, however, to tell a person with no background in chemistry what the science is about and how the chemist thinks and operates and what the impacts of his endeavors are on society.

After eight years of teaching such a course, it appears that this type of treatment might also even serve as an introduction to the science for majors of chemistry and other professional groups. It would be well to give budding chemists an over-all idea of the field, so that they would have some basic notion why they are to study the special courses of their curricula, which must appear to them as a series of disjointed topics in chemistry. The difficulty of instituting such a plan as the creation of a beginning course in orientation in chemistry lies in the fact that there is not time to place this course into a four-year curriculum leading to the B.S. degree. A chemistry department, which is accredited by the American Chemical Society, naturally will follow the general scheme of chemical education as evolved by the chemists of the country and as administered by the Accrediting Committee of the American Chemical Society.

*Course content.* Two methods of approach appeared possible in such a chemistry core course. On the one hand, the historic approach might be taken and a few examples of famous problems and investigations in chemistry might be discussed. The scientific method might thereby be illustrated, in the hope of imbuing the student with the scientific approach with the expectation that he could learn to apply the process to problems in his own life. However, this first method appears to be entirely too meager a fare. It does not present

to the individual the place of chemistry in contemporary civilization. It fills only half the bill and does not broaden the horizon sufficiently. Hence the second method was adopted: to tell the student *about* chemistry as it actually is today. It is hoped that the limited presentation in no way cheapens the subject. The treatment is not a course in chemistry in ten easy lessons!

After six years of teaching this course a textbook<sup>8</sup> was written for it. It contains the following chapters:

- I. The Concept of Matter: Material Things, Physical Changes, Chemical Elements and Compounds, Chemical Change
- II. The Concept of Energy: Thermodynamics, Mass-Energy Equivalence, Electrical and Radiant Energy
- III. Fundamental Particles: Atoms and Molecules, Electrical Particles, Atomic Structure
- IV. The Scientific Approach: The Scientific Method, The Scientific Attitude
- V. The Divisions of Chemistry: Theoretical Chemistry, Inorganic Chemistry, Organic Chemistry, Biological Chemistry, Analytical Chemistry
- VI. Applied Fields of Chemistry: Chemical Engineering, The Metal Industries, The Petroleum Industry, Chemotherapy, Food, Rubber, Plastics, Textiles, Household Chemistry, General Reading List

It is believed that the topics cited give a fair picture of present-day chemistry. The attempt is made to arouse the student's interest. However, the experience gained in this work seems to indicate that a great many students have little intellectual curiosity. They are not mature enough to want to know about the world around them. It means that the group must be carried on a certain level of attainment, not too high or else many will fail.

In teaching chemistry on the beginner's level there are two methods of approach possible. The atomic concept may be introduced at once and then the facts and theories can be discussed in terms of the modern language of the science. This method is easier for the teacher since he can carry on his lectures on the accustomed plane in terms of atoms and mole-

<sup>8</sup>George and Ruby C. Glockler, *Chemistry in Our Time* (New York: Appleton-Century-Crofts, Inc., 1947).

cules. However, it does not show the student how earlier generations of chemists have struggled through these last centuries trying to evolve a consistent scheme of thought, based on experience and experiment and culminating in the present complex of chemical ideas.

It is the second method which is used in this core course. The student is made aware of facts by demonstration. The need of new words is shown. Different ideas and experiences demand additions to the vocabulary. The notions of "matter, different substances, physical changes and the observation of more permanent or chemical changes" are stressed. All the time the important question is held before the class as to what the detailed constitution of matter could be, so as to permit a description of the things observed in this physical world. For example, the facts of definite composition are illustrated and discussed, always stressing the question: Just how can matter be constituted so as to explain this remarkable fact of observation? Or, again, how can it be that gases of varied composition do, after all, behave in such uniform manner as is expressed by the gas laws? In this atomic age one would expect that at least the better educated section of the people should know about the interconversion of matter and energy. Surely, a college graduate should know something about nuclear reactions, Einstein's equation, the chemical effect of x-rays, gamma rays, and neutrons; and topics such as plastics, synthetic rubber and gasoline, chemotherapy, and photosynthesis should be presented to him at least once in his formative period.

*Teaching and evaluation problems.* The temptation always exists to staff a course of this kind with young instructors. Their lower salaries are an inducement in that direction. Furthermore, the older and more experienced men are usually better equipped to handle upper-division courses and work on the graduate level. They are also burdened with committee work, special assignments, and research work which must be carried on if the department is to maintain its position in the chemical field. However, the administration of the College of Liberal Arts adopted the policy of handling these core courses with experienced teachers. This policy resulted in an additional load being placed on older staff members. In the case of chemistry the extra load was assumed by the department

head, because of the conviction that the science of chemistry should be brought to the attention of all the people by someone who believes in the program and hence would work toward a fair trial.

A series of four class periods a week for one semester (sixteen to seventeen weeks) is offered with extensive demonstrations. About six well-known educational films are used and the possibility of expansion in this direction is being considered. One of the weekly hours is used as a question period. It has worked unexpectedly well even with large classes of several hundred students. It is believed that one reason for this lies in the fact that the textbook used contains a set of questions *and* answers at the end of each chapter for study and review. This latter feature makes it possible for the student to learn the type of answer that he is expected to know.

No doubt it will be said that the whole process of learning is thereby reduced to a memorizing task and that the student will not learn the thought processes involved in scientific reasoning. However, the course is not intended to produce scientists; moreover, the difficulty can be resolved by the proper type of examination. It is always possible to include enough thought problems to test the student in reference to his ability to reason in this area and to comprehend the maxims of chemical discipline. The examination calendar is announced early in the semester and the topics covered in each one of the three written tests are clearly set forth.

A typical examination, covering pages 88 to 149 of *Chemistry in Our Time*, follows:

Examination  
Introduction to Physical Science 11:26  
April 5, 1948

1. Give the general formulas for the following compounds: Metal oxides (Metal = M); Metal hydroxides (Metal = M); Metal sulfates (Metal = M); Metal phosphates (Metal = M); Organic alcohols; Organic aldehydes; Organic ketones; Organic acids.
2. Complete the equation:  $\text{Ca}(\text{OH})_2 + \text{H}_2\text{SO}_4 \rightarrow$   
What type of reaction is it?
3. How much calcium hydroxide (in grams) would have to be dissolved in one liter of solution to contain one-tenth the amount represented by the formula  $\text{Ca}(\text{OH})_2$ ? ( $\text{Ca} = 40$ ;  $\text{O} = 16$ ;  $\text{H} = 1$ ).
4. How much sulfuric acid (in grams) would have to be dissolved in one liter of solution, in order to contain one-twentieth the amount represented by the formula  $\text{H}_2\text{SO}_4$ ? ( $\text{H} = 1$ ,  $\text{S} = 32$ ,  $\text{O} = 16$ ).

5. Mention some metal alloys in everyday use.
6. Define the following types of chemical reactions: (a) Combination; (b) Decomposition; (c) Displacement; (d) Oxidation; (e) Reduction; (f) Neutralization; (g) Hydrolysis; (h) Electrolysis.
7. Complete the following equations:  $\text{NaCl} + \text{AgNO}_3 \rightarrow$ ;  
 $\text{NaBr} + \text{AgNO}_3 \rightarrow$ ;  $\text{NaI} + \text{AgNO}_3 \rightarrow$ ;  
 $\text{NaAt} + \text{AgNO}_3 \rightarrow$ .
8. Complete the following equations:  $\text{HCl} + \text{NaOH} \rightarrow$ ;  
 $\text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow$ ;  $\text{H}_3\text{PO}_4 + 3\text{NaOH} \rightarrow$ ;  
 $\text{H}_4\text{SiO}_4 + 4\text{NaOH} \rightarrow$ .
9. Complete the following equations:  $\text{Cl}_2 + 2\text{NaI} \rightarrow$ ;  
 $\text{Br}_2 + 2\text{NaI} \rightarrow$ .
10. In the electrolysis of water, two gases are formed.  
(a) Name them and give the tests for each gas;  
(b) give their relative volumes.
11. The density of metallic gallium is 5.9 and the density of solid arsenic is 4.7. Estimate the density of solid Germanium.
12. Write the following chemical formulas (use the periodic table): The oxide of germanium (Ge); The chloride of zinc (Zn); The bromide of antimony (Sb); The iodide of scandium (Sc);
13. What is meant by the heat of a chemical reaction?
14. Define the word "energy."
15. Mention four different forms of energy.
16. Define the terms: (a) calorie; (b) specific heat; (c) heat of fusion; (d) heat of evaporation.
17. How much heat is obtained on burning 6.02 pounds of carbon? It is known that the combustion of one pound of carbon is accompanied by the emission of 3.57 million calories.
18. How many micrograms of matter will have to be changed completely to energy in order to yield the same number of calories as calculated in question "17"? It is known that one microgram of matter on complete conversion to energy, will yield 21.49 million calories.
19. In the case of gravitational energy (waterfall) it is known that energy is measured in terms of three factors: height  $\times$  rate of flow  $\times$  time = energy. State the similar relation in the case of electrical energy, using the conventional words, volts, etc.
20. Complete the equation showing the chemical reaction going on in the lead storage cell on discharge:  $\text{PbO}_2 + \text{Pb} + 2\text{H}_2\text{SO}_4 \rightarrow$
21. What would happen if the materials used in the lead storage cell (finely powdered Pb, finely powdered  $\text{PbO}_2$ , liquid  $\text{H}_2\text{SO}_4$ ) were intimately mixed in a vessel?

*Laboratory work.* It is an old contention with teachers of chemistry that the subject cannot be grasped unless the student carries on some laboratory work. Chemistry is primarily an experimental science and no amount of lecturing and demonstration will really get the subject matter across. This type of argument is certainly sound enough when applied to

chemistry majors and engineering students, premedical students, and other professional groups who surely should get hold of the subject in a thorough fashion, since they need this knowledge in their respective professions. In the case of a pandemic course there is not enough time to make laboratory exercises more than a perfunctory attempt to maintain a tradition. Moreover, the expense would be quite prohibitive in relation to the results to be expected. Neither is space available to handle this additional load. At any rate, eight years' experience seems to indicate that students can learn enough about chemistry from lectures, demonstrations, movies, and a question period to accomplish the primary aim, that is, to broaden their outlook in life and enable them to realize how this particular field has helped to create the present civilization and how it influences their daily lives. This course differs from the ordinary first-year chemistry course in the lack of laboratory work. Furthermore, the topics considered are not covered so thoroughly, but many more phases of chemical knowledge are touched upon.

*Integration.* It should be noted that the physical sciences (physics and chemistry) are given in separate semesters. First of all, both subjects cover a very large field of human knowledge and these areas can hardly receive justice if treated together in one of the so-called integrated courses of general science. Aside from the problem of finding the proper staff members sufficiently familiar in both areas, it seems that some work should be left to the student. Let him do some of his own integration! It seems best to present the subjects from the point of view of the physicist and the chemist separately. In areas of common concepts it is definitely wholesome to have the student hear about these topics from different lecturers. Their approach will be distinctive, and to be exposed to this varied treatment is an advantage to the learner. Even some repetition is desirable, for it brings with it the opportunity of better understanding. After all, the student is exposed to a great many fundamental concepts in both of these courses and to hear some of them a second time is all to the good. Repetition is surely a most powerful tool of the learning process.

*Scientific method.* The ways of the scientist are illustrated throughout the course. Every opportunity is taken to point out how chemists have carried on observation in the physical

world surrounding them and how they have attacked their problems and attempted to solve them. It is shown how mental constructs have been created and how a whole system of coherent thought and theory has been evolved in order to "explain" the phenomena of the physical world. Great stress is laid on the proposition that there exist in every discipline fundamental concepts which are basic to the science and which at the moment cannot be further defined. It is pointed out that ideas change, that new concepts arise, and that scientific thought is not static but a dynamic phenomenon. Discussion of the scientific method has been placed after the several introductory topics so that a body of knowledge exists on the basis of which the general discussion can be built.

*Improvements.* The experience gained so far would indicate that the lecture-demonstration method is satisfactory. No laboratory work is contemplated. It is felt that the students get a sufficient idea of the subject to claim that they have learned something *about* chemistry. However, the lecture demonstrations need improvement. The experiments on the lecture table are carried out on much too small a scale for students to see them from the back of a large lecture room. Such demonstration apparatus must be made of much larger dimensions. While some attempts have been made with large test tubes and a few oversized molecular models, the problem will require much more work and expenditure before it is solved satisfactorily. A better use of films should also be developed since they are so obviously fitted for mass demonstration.

## The Science Program in the Boston University General College

AFTER a considerable period of study of the problems of and need for general education at Boston University, President Daniel Marsh announced the formation of Boston University General College and appointed Judson Rea Butler dean and director on March 29, 1946. This college was created as a separate unit to permit complete freedom in constructing a curriculum and in choosing a staff with the single purpose of general education in mind. Without this autonomy it would have been difficult to set up a consistent general education program of this character. As stated in the catalogue, the aim of the General College is to offer the student a *general education* in which emphasis is placed on the relationships within and among the principal fields of knowledge, rather than upon specialized training in any one vocational or cultural subject. Its program differs widely from that of most liberal arts or professional colleges, in which the student chooses his courses of study from a wide variety in many different fields. Instead, the two-year curriculum of the General College includes material from five broad areas of human interest, taught without reference to the lines of demarcation which normally set off one subject from another: natural science, human relations, English and the humanities, political economy, and educational and vocational guidance.

The aim is *fusion* within each of these broad fields, and careful *integration* among them. The subject matter of physics, chemistry, biology, geology, and astronomy thus are fused into the single course in science, and science is correlated in turn with history and government and the social sciences, with English literature and the humanities, and with guidance.

By Wesley Newell Tiffney, professor of biology and chairman of the science department, Boston University General College.

Unity is an inherent characteristic of the world of nature. The separation of such subjects as physics, chemistry, and biology into separate disciplines, while a necessity of convenience in research, has not destroyed the essential interdependence of all science. Likewise, social science cannot be treated adequately in isolation from the relevant data of science. By bringing these subjects into their logical relationships, a truer perspective is established early in the student's career. For, while the advanced student of biology in a conventional college eventually may be led to an understanding of the interplay of chemistry, physics, and biology in living organisms, such understanding is seldom achieved by the majority who never pursue the subject beyond its elementary stages.

This more natural method of presentation neither precludes thoroughness nor necessitates a superficial survey of the subject matter. In fact, the student's knowledge is enriched and his understanding is intensified and broadened by this emphasis on relationships. Instead of acquiring mere isolated facts and techniques the student develops a system of knowledge. In contrast to the conventional subject-matter approach, the purpose of general education is to equip the graduate of the General College with a wide understanding of the world about him and the social system in which he lives, rather than with detailed but more or less isolated knowledge of certain particular subjects. It may be seen that the college was designed to provide an integrated liberal education in two years of academic work and to prepare the student to matriculate elsewhere in the university at the junior-senior level in some specialty of his own choosing. The General College is not therefore to be considered a two-year college leading to terminal education, but rather a place in which the principles of general education are allowed to operate for the first two years of the student experience.

#### DESCRIPTION OF THE SCIENCE PROGRAM<sup>1</sup>

Science is so vitally a part of our national and international life and culture that it is highly desirable for today's citizens to have an appreciation of its achievements of an intellectual

<sup>1</sup>Members of the General College science staff who have contributed to the development of this course are: Colin H. Kerr, Charles R. Holbrook, Ernest H. Blaustein, Wilma Harris, Charles R. Whelan, and William Happ.

and philosophical nature and its utilitarian applications, as well as an understanding of its dangers and limitations.

The purpose of the science program is to give a clear understanding of the achievements of the principal sciences, to demonstrate the relationship between the laws of science and the world of nature, and to promote a thorough understanding of the scientific method in order to show how scientific development has made for cultural progress and growth. The method of presentation is planned not only to make the student familiar with the fundamental principles of each science but also, by acquainting him with the role of science in the modern world, to provide that scientific understanding essential to a liberal education.

The science program is a two-year course. For the first year, the students meet each week for four hours of lecture and one hour of discussion, demonstration, and laboratory; for the second year, they have three hours of lecture and one hour of discussion, demonstration, and laboratory a week.<sup>2</sup> The lectures (for large groups) are supplemented with all feasible types of visual aids, such as motion pictures, lantern slides, and large-scale demonstrations. For the best understanding of the material, the science department feels that, where possible, all lectures should be illustrated.

Small groups of students (20 to 25) meet with trained section men, who have attended all lectures, to discuss the material of the lectures and the assigned reading. The section meetings provide opportunity for personal contact between the faculty and students, and permit the faculty to keep in close touch with student comprehension of material and problems arising from it. Small-scale demonstrations are presented in these section meetings, and where feasible, clear-cut significant laboratory exercises are assigned. No laboratory exercises involving the assembly of intricate apparatus or productive of dubious or obscure results are used, since such exercises all too often confuse rather than add to understanding. Consequently many standard laboratory manuals have been discarded and a new series of experiments is being designed.

In addition, conference periods are provided in which students may meet with faculty members for personal discussion

<sup>2</sup>We are at present considering extending the section period to two hours a week for both years to allow for more adequate treatment of the material.

and consultation. These conference periods provide 24 additional hours a week when designated faculty members are available during stated hours in a room set aside for the purpose. The conference rooms are equipped with demonstration and reference material pertinent to the lectures of that week.

The science course is not divisible into sections or fields of science. It contains material selected from astronomy, biology, chemistry, geology, and physics, rearranged in a sequence, in which the emphasis is on understanding and significant relationships rather than on accumulation of facts. This arrangement is based on the belief that it is not desirable to require the student who has no intention of using the sciences professionally to take the conventional courses with their emphasis upon special techniques and encyclopedic knowledge, an emphasis which obscures the relationship of science to the general scheme of things both from an academic and from a practical point of view. We believe that the general student will benefit more in a balanced point of view, in practical knowledge, and in richness of experience from an inclusive course which touches upon all the more prominent manifestations of the natural world around him and endeavors to show the interaction of these phenomena and their significance to everyday living, than he would from one or two intensive introductory courses dealing with one or two restricted specific subject areas. Indeed, our criticism of the usual college beginning course in science for the general student is that it is at the same time both intensive and introductory—it gives the usual student too many details and technical terms and yet cannot manage to get beyond the elementary stage of the subject to permit a coherent mature view of the whole subject, with details in their relative importance and relationships. Consequently, the subject remains an isolated compartment of knowledge without significant meaning or bearing on his life in the future. Such a standard elementary course is useful to the preprofessional student in a particular field, but does not contribute effectively to the enrichment and integration of the program, or to the understanding of the general student.

We do not feel, however, that in becoming inclusive our course has become superficial. Condensation has been achieved by the critical choice of topics. Subjects of major importance

are presented thoroughly in all their aspects, while those of interest chiefly to specialists have been eliminated. Condensation without loss of thoroughness is achieved also by the two-year integrated course plan, in which time is gained by elimination of the overlapping and recapitulation that necessarily occurs in discrete courses. Again, we make extensive and intensive use of all available visual-aid material, which conveys ideas more vividly, quickly, and effectively than lecture alone. In the small laboratory-discussion sections, demonstrations and experiments are carefully chosen to permit students to see and manipulate the objects they are studying, but to eliminate the necessity for spending three-fourths of the time hunting for the object under the microscope or trying to connect a complex apparatus into a gas-tight system. Such exercises are unquestionably valuable for the embryonic professional scientist but are a frustrating waste of time for the general student. Again, we employ technical language sufficiently for the student to get an idea of its precision and usefulness, but we do not attempt to present to him a basic dictionary of technical terms such as would be indicated for a prespecialist. These time-gaining devices all contribute toward the achievement of a course that is both inclusive and thorough.

Since the presentation of the material is sound and thorough this course may be used as a basis for advanced study in any of the fields of science. However, in view of the fact that the course is designed primarily for students who do not plan to specialize in one of the sciences, a series of bridging sections has been set up to supplement the regular course for those who do expect to go on in science.<sup>3</sup> These "tutorial" sections consist of standard laboratory exercises, discussion and study, not replacing the general basic course but extending over and beyond it. This arrangement represents a satisfactory compromise between the education-for-specialization and the general education schools of thought, and does not involve more

<sup>3</sup>An alternative though less satisfactory plan is to advise the student who is contemplating advanced scientific work to take a laboratory course in the field of his primary interest in summer school, in order to develop the laboratory techniques required.

than 5 to 11 percent of the student body.<sup>4</sup> It is our belief that the need for such a compromise course will disappear as faculties of liberal arts colleges and graduate schools accept and adapt to the principles of general education.

Although this course is planned to fulfill the needs of the great majority of students who do not expect to become scientists, we feel, nevertheless, that for two reasons it is an excellent background for a prospective scientist. First, it deals with the social impacts and responsibilities of science, an increasingly important point of view which is almost wholly absent in standard science curricula. Second, it deals with all the sciences, and so gives the prospective scientist a complete, rounded, well-balanced background in science itself, a result which the system of free electives which permitted too early and too narrow specialization within a single branch of science frequently failed to achieve.

Before each lecture or group of lectures each student receives a mimeographed outline which serves as a guide to the understanding of lecture material and assigned reading, and which he is expected to use for the purpose of orientation toward the new material. Pertinent references are coordinated with each section of the outline. These references may be a paragraph or a chapter in a standard textbook, an essay or a biographical sketch. At the same time problems are given, to be worked out by the student and discussed in section meeting.<sup>5</sup> No single existing textbook is adequate for the course; indeed, in the light of our present experience a single textbook would not be desirable. Reading assignments made in a wide variety of source materials give the students some idea of the bases of knowledge and a chance to evaluate conflicting points of view and develop critical judgment. For this purpose an extensive library is necessary and considerable thought and care must go into its building. Our reference

<sup>4</sup>The figure would seem to indicate that previously colleges have apparently forced 89 to 95 percent of their students into "specialist" courses against their needs and desires, and certainly before many of them had any real idea of which specialty they wished to enter, as anyone who has attempted to advise students choosing their "majors" for the first time can testify.

<sup>5</sup>These problems are frequently of the "case method" type, taken directly from a life situation and not synthesized for the purpose. Such problems, if fortunate, include areas of learning from the social sciences, economics, literature, and so on, as well as from science. The problems may also be of the laboratory or mathematical variety.

book list is still in process of assembly and is regarded by us as one of our most useful teaching aids.<sup>6</sup>

#### GUIDING PRINCIPLES IN COURSE ORGANIZATION

The outline of the course which follows should be read with certain basic principles in mind. First, and perhaps most important of these, is that specific course content is of secondary importance, since the course is organized about the functions of general education (to integrate knowledge, to serve the needs of society, to stress basic concepts). In the hands of a research scholar this outline could become encyclopedic in nature; such a development would be a basic mistake, since it would not encourage the student in clear thinking, critical evaluation, and the formation of sound, constructive attitudes and habits which are retained long after facts are forgotten. Several of the ideas emphasized here would in the hands of other teachers be properly relegated to a secondary position, in accordance with the differences in their backgrounds, experiences, and points of view.

However, there is one point we wish to emphasize: if an idea is presented at all it should be explored in all its facets and developed to its most valuable level as, for example, its literary, artistic, social, and economic as well as its scientific purposes. Such an exhaustive treatment may require two or more lectures to cover the idea properly, a practice which we recommend with the warning that the whole should have the unity, coherence, and emphasis which can come only from excellent coordination and integration, usually directed by one person. Each member in the teaching team of a general education faculty should not think of himself as covering one aspect of a single course—he is not teaching social science or science, but rather is preparing the student for effective adjustment to his physical and social environment.

A second principle, which it is sometimes difficult to observe, is that the sciences should be fused into one unit. We do not consider it desirable to divide the physical from the biological sciences, for we hold that where two or more sciences use techniques and knowledges in common they *should* be integrated. For example, a study of the architecture and behavior of mat-

<sup>6</sup>In the past two years we have assembled a library of some 30,000 volumes. In the case of particularly useful books there may be as many as 400 copies of the same title.

ter is basic to an understanding of physics, chemistry, physiology, and astronomy. Such material should be covered once in considerable detail, and referred to thereafter whenever pertinent. On the other hand, there are areas where the various sciences do not impinge directly on one another; in such areas no fusion is practicable and none should be attempted.

The third principle to be noted in the outline which we follow in Boston University General College is that the science course constitutes a partial foundation for the other areas of learning. Inheritance studies, for example, are used as a basis for the understanding of many social problems; the anatomy and functions of the nervous and glandular systems of the body likewise are used as a background for the study of mental phenomena, personality, and the general field of social adjustment. A knowledge of the eras of earth history in geology is basic to the concept of biological evolution and is a starting point for the study of anthropology and some of the principles of archeology. Newton's observations on motion and gravitation form a background for the study of seventeenth century literature, art, and certain ethical, social, and economic problems, all of which should make the presentation of Newton's laws less pedantic and more vital to the student. A knowledge of the physics of sound is fundamental to a study of the physiology of the ear and an understanding of auditory sensation, and the whole can be used in the humanities staff as the basis for a discussion of music and its appreciation. Further areas of fusion and integration will be noted on the margin of the outline.

The fourth principle of importance is that historical development of thought in science and philosophy is a constant underlying theme of our presentation with the emphasis on ideas rather than chronology.

OUTLINE OF THE TWO-YEAR SCIENCE COURSE  
 INTEGRATION WITH OTHER  
 SUBJECTS<sup>7</sup>

SCIENCE OUTLINE

English Logic, methods of reasoning, methods of expression, readings on early and modern science; <i>The Education of Henry Adams</i>	<i>Science Background — General</i> I. Description of the sciences, their method and scope
Social Subjects Hypothesis, theory, and law developed as in science	Definitions of biology, astronomy, chemistry, geology, and physics; attitudes of science; motives and interests man has in science, techniques of thought and philosophy of science
Political Economy Economics as a science, political science, the nature of law, methods by which men discover truth and standards	II. Matter and energy The architecture of matter, atomic structure, interaction of atoms, classification of the elements, a concept of energy, kinetic theory of matter, matter and energy defined
Social Subjects, Guidance, and Political Economy Use of statistical measurements, I.Q., public opinion polls, price levels	III. Mathematics and its relation to science Systems of measurements, mass, weight, position, time, temperature, and their origin; concepts of function, constants, power, root and numbers, the use of equations; the use of the statistical method; general symbolism and vocabulary of mathematics
	<i>Biological Sciences</i> IV. Life Living vs. nonliving; the cell, its anatomy, physiology; use of gas laws, solutions, ionization; cellular reproduction

7. Such integration calls for the highest degree of cooperation among the whole staff, and entails a great many hours of conference work in exploring and adjusting the program. It also greatly increases the significance of the subject matter of all courses in the minds of the students.
8. Students whose test results indicate a weakness in the fundamentals of mathematics are required to take a course in remedial mathematics, without credit, to correct this difficulty.

OUTLINE — (*Continued*)INTEGRATION WITH OTHER  
SUBJECTS

## SCIENCE OUTLINE

## Social Subjects

Customs and mores of tribes and cultures of men

## V. Reproduction

Survey of types, mammalian reproduction; principles of mitosis and reduction division

## English

Readings in autobiography, writing student's own autobiography

## Social Subjects

Inheritance as a social problem, mental derangement, etc.

## Economics

Population studies

## VI. Study of inheritance

Contrasting theories, popular, scientific, Mendel's work, gene and chromosome theory; applications to agriculture, medicine

## English

Thoreau, *Walden* and a naturalist's approach to biology

## VII. Survey of plant and animal kingdoms

(Only larger groups are covered here to permit understanding of evolution and ecology)

## All subjects

Evolution as a theme of art, literature, thought; philosophical implications; origin of state and social institutions; reading in Darwin

## VIII. Concept of evolution

Contrasting theories; Darwinian thought; evidence from anatomy, embryology, taxonomy, etc.

## Social Subjects

Items IX, X directly related to psychology of perception, psychology of personality, psychopathology, psychoanalytic theory, etc.

## IX. The organ systems of the mammalian body

Digestion, circulation, excretion, respiration, glandular secretion, nervous system. Each system considered from its (1) comparative anatomy, (2) physiology (with emphasis on significance for health), (3) embryology

OUTLINE — (*Continued*)INTEGRATION WITH OTHER  
SUBJECTS

## SCIENCE OUTLINE

**English**

Reading in literature with special emphasis on the depiction of psychological states or types

**Psychology**

Sensation, perception, social patterns, and art

**Humanities**

Staff members of humanities give lectures in science section on music. Psychology staff gives lectures on perception, ear and eye, in science section. Also with physics of light humanities staff gives demonstrations and lectures on color and perspective in art.

**Psychology**

Sensation, perception, aesthetic reactions

**Social Subjects**

Disease and social problems

**English**

Book review and report on Zinsser's, *Rats, Lice, and History*

**Economics related to agriculture****Social Subjects**

Social problems

**X. Sensory discrimination**

Types compared and discussed; effects, advantages and limitations imposed on man's science, philosophy, etc., by sensory processes

A. Sound (physics and biology)  
Its nature, history of our knowledge, periodic motion, waves, energy properties, acoustics, musical scale, instruments, art, and music. The structure and function of the ear

**B. Light**

History, methods of illumination, image formation, lenses and reflectors, refraction, prisms, light waves, photons, color, the spectrum, art and color. The eye: anatomy, psychology of sight

**X. Sensory discrimination (continued)****C. Other senses**

Touch, taste, olfactory, balance

**XI. Man and disease**

Work of Pasteur, Koch, Tyndall, Lister, etc., organisms causing disease, factors aiding or precluding disease; basic immunology, sanitation and public health

**XII. Economic Biology**

Zoology, botany, agriculture

OUTLINE — (*Continued*)INTEGRATION WITH OTHER  
SUBJECTS

## SCIENCE OUTLINE

## Social Subjects

Climate and man studies

Economics and literature

Effect on man of climate  
and geography

Political Economy

Geographic determinants,  
geopolitics

English

Steinbeck, *Grapes of Wrath*

## Economics and History

Mineral wealth and its effect on man, imperialism, expansion of old world civilization

## General survey

English

Literature and thought of the ancients

## Social Subjects

Physical and social anthropology

## Economics and History

History from Greece to 1600 A.D.

## Classical and medieval literature and philosophy

The legacy of early civilizations, political, economic, etc.

*Earth Sciences*

XIII. The larger features of our earth  
Atmosphere, troposphere, stratosphere, temperature, pressure and circulation; weather, Bjerkne's air mass analysis theory; hydrosphere, lithosphere, continents, deep - sea basins

XIV. Erosion and sculpturing of earth  
A. Weathering; erosion, sheet, stream and river; ponds and lakes; subsurface water; oceans and ocean currents; ice, mountain glaciers, continental glaciers; prominent local features  
B. Mountains, their formation and destruction; volcanoes, deformation of the earth's crust, earthquakes; origin and history of mountains, land forms

XV. Mineral resources  
Economic geology, minerals, rocks, ores, etc.

## XVI. Earth History

Pre-Cambrian era, Paleozoic era, Mesozoic era and reptiles, Cenozoic era and mammals; evolution of life and time; strata and life; paleontological records of the primates

*Astronomy*

XVII. Early science  
Survey of pre - Greek scientific thought; science in Greece and Rome; the Ptolemaic system, Copernicus and the heliocentric system; work of Galileo, Brahé, and Kepler, Bacon, Descartes, Gilbert

OUTLINE — (*Continued*)INTEGRATION WITH OTHER  
SUBJECTS

English, Social Subjects, Economics and History

The effect of theories of science on life and thinking of the time; cultural, ethical, literary and artistic; development of naturalism and rationalism

Philosophical concepts

Social Subjects, Economics, and English

Industrial Revolution past and present; technology and society, T.V.A., etc.; labor unions; various forms of government; the economy built on industrialism and science

English and Humanities

Changes in methods of communication; and changes of attitude on the part of writer and artist toward the material medium of art during the nineteenth century

## SCIENCE OUTLINE

## XVIII. Sir Isaac Newton

Study of Newton's life and background; his laws of motion, mechanics of astronomy, mechanics in physics and everyday life; laws of gravitation and mechanics of astronomy, application to everyday life; Newton's work on optics, the spectrum; Newton - Leibnitz and calculus

## XIX. The solar system and universe

The sun, planets, satellites, comets; nebulae, galactic systems; space and motion; hypothesis of Laplace, bi-parental and monoparental hypotheses of earth origin

## XX. Heat

Kinetic theory; work, power, conservation of energy, quantity of heat, temperature; heat engines, their history and development

## XXI. Electricity and magnetism

Static electricity, charge, induction, conduction; magnetism, fields of force—magnetic and electric; motion and magnetism; current electricity, potential, Ohm's law, voltage, quantity of electricity, temperature; alternating and direct currents, generators, motors, transformers

## XXII. Electricity and matter

Conductors, solids, liquids and gases; piezoelectricity; production of heat and light; electrons, protons, neutrons, radioactivity, isotopes; modern physics of Maxwell, Planck, Einstein, and others

OUTLINE — (*Continued*)INTEGRATION WITH OTHER  
SUBJECTS

## SCIENCE OUTLINE

## All subjects

Social psychological, philosophical factors and effects in Renaissance, Industrial Revolution and modern period

## XXIII. Electricity and radiation

Electromagnetic waves, electron tubes, (radio tubes) Cathode ray tubes, etc.; spectrum of hot objects; the quantum idea and quantum mechanics, x-rays, cosmic rays

## XXIV. Electricity, waves and radiation.

General background of wave action, wave phenomena, waves and sound, electromagnetic waves, visible light

In conclusion there are two points which should be stressed. First, the type of examination written for the course will largely determine the character of the course. For example, if factual questions are constantly used, then facts alone will be memorized by the student and the fundamental aims of the course will be lost. The subjective type of examination is probably easiest to design to fulfill the needs of a course such as this but it is difficult to grade impersonally and fairly, particularly if the number of students is large. We feel that it is possible to write objective examinations that stress the interrelationship of material and basic ideas. While this type of examination may take hours to prepare, it has the distinct advantage of covering much more territory than the subjective type of examination and of lending itself to more fair and impersonal grading.

The midyear or final examination, however, is combined into a single comprehensive test which covers the student's entire program. This test is of six hours duration, divided into two three-hour periods, so designed as to draw upon knowledge and understanding acquired from the lectures, discussion, and readings of all the courses. Seventy-five to one hundred questions are published a month or more before the examination period and six to eight of these are selected for the final examination. The examination grade is the same therefore for all of a given student's courses. Such a system

of examination forces integration in the student's study program as well as in course lectures and discussions.

Second, we do not regard this outline as ideal. At present it is working rather well, but we suspect it is only one of many versions which we shall write.

## The Single-Science Type of Scientific-Appreciation Course

The end of World War II has confronted American Education with two highly disturbing facts. The first fact is that the survival of modern civilization depends upon an understanding and control of scientific techniques whose power for good and evil dazes human imagination. The second fact is that our teaching and our equipment for teaching this understanding and control are woefully inadequate.

Science teaching . . . (simply) is not ready for the responsibilities which it must nevertheless assume. Nor is education ready in other subject areas for its obligations in an atomic age. The time is short. The task is nothing less than to lift a whole generation of American citizens to a level of knowledge and human goodness which has hitherto been attained by only a small fraction of our people.<sup>1</sup>

This statement, published about two years ago, opened a report of a special committee of the American Association for the Advancement of Science. The situation is certainly no less acute today, nor the remedy any less urgent, than it was at the close of the war. If anything, matters are worse, or at least our desperate plight is more widely recognized. Time is of the essence.

General comprehension of the nature and the potentialities of science, and that right soon, is now one of the conditions of salvation. A generation ago "general science" and "science surveys" were thought of, at least by many men of science, as an outcropping of intellectual dilettantism. Today a wide and an early "appreciation" of science is no less than a matter of life and death for our civilization. The responsibility now devolving upon science teachers has few parallels for momentousness.

Ever since the day of early general science and science survey courses, a general feeling seems to have been abroad that scientific appreciation can be attained only by exposure to a

By Lloyd W. Taylor, professor of physics, Oberlin College.

<sup>1</sup>School Science and Mathematics (February 1946).

potpourri of at least several of the basic sciences. There is no doubt a great deal to be said for this point of view. Certainly no one of the sciences has a monopoly on the "scientific method," and there could conceivably be some notable advantages in approaching that elusive concept from several angles. Notwithstanding some serious drawbacks in the multiple-science approach, it deserves the continued study that it is receiving.

But standing in the way of general use of a multiple-science approach is an almost complete lack of properly qualified teachers. Even after the educational world has been "sold" on the idea, it will take a great many years to prepare the required number of teachers. That number will be very large, if we are "to lift a whole generation . . . to a level of knowledge . . . which has hitherto been attained by only a small fraction of our people." Is the time available for so vast an undertaking? It was two years ago that Chancellor Hutchins said that science had five years to save the world. This deadline may perhaps be generously extended. But to extend it far enough to allow for the production of a generation of teachers adequately trained to administer multiple-science courses to all college students would be tantamount to saying that no emergency exists.

The fact is that, in the present state of the world, the time factor may not safely be disregarded. This places a grave handicap on a multiple-science approach injected, as it must be, into an educational system whose science teachers are at present almost exclusively single-subject specialists. Before such an approach can be made, on a scale large enough to meet the requirements of the times, we shall have to solve the problem of wholesale training, or at least retraining, of teachers who are to administer the multiple-science courses. If done properly (and we can scarcely contemplate doing it any other way) such training could scarcely deliver its large-scale products for decades, whereas, according to some prophets of doom, only years are available.

One alternative is the single-science type of scientific-appreciation course. For this the typical teacher now in the profession is much better prepared. He has at least the science-subject-matter foundation on which to build the historical, philosophical, and educational superstructure of appreciation. The

thesis of this article is that the single-science type of scientific-appreciation course has some notable advantages for the more immediate aspects of the solution of the problem of universal science education, whatever may be said of the ultimate solution.

Before describing the single-science course, it might be well to state what it is not. It is not the present conventional introductory course. The conventional general course in any science is primarily aimed at the indoctrination and early preparation of science specialists. It is typically administered to all beginning students, even though the budding specialists among them usually constitute only a small proportion of the students under instruction. It is for this reason that single-science courses have acquired a bad name with educators having broader aims in science courses for general education. A generous core of factual material is, of course, necessary, even for the broader type of course. The difficulty with the conventional course is that it stops when the factual material has been set out in an orderly fashion, instead of using that material as the medium with which to construct scientific appreciation. It is as though an artist should assemble the canvas, brushes, and all the tubes of paint required for the production of a masterpiece and then leave them in an orderly arrangement in his studio, on the assumption that, since all the materials were present, the masterpiece was complete.

A number of years of experience have convinced the writer that it is entirely feasible so to design and administer a single-science course as to make of it a fertile culture medium for the growth of broad science appreciation. Experimentation to date, however far it may have fallen short of perfection, has taken the form of embedding the content of a conventional beginning course in a fairly extended matrix consisting primarily of the history of its development. The philosophy of science is not avoided. It cannot be in such a venture. But the historical material dominates. Ideally the plan consists of limiting the case-study method to a particular science, but expanding it to cover most of the major cases within that science. Not all the cases lend themselves equally well to that approach, of course. But the large multiplication of cases provides an aggregate effect which is capable of furnishing the substantial equivalent of the perfection attainable for indi-

vidual cases by limiting one's choice to the more ideal examples.

The single-science course, thus broadened to meet the current need, may not be the final solution of the problem of inculcating a wide general appreciation of science. But as a short-range measure it seems to constitute a solution to the dilemma created by the urgency of time. This urgency puts a heavy premium on the maximum use of existing channels of instruction and, as a corollary, on the minimum departure from conventional modes of instruction consistent with the new and broader objectives of science in the educational enterprise. We must reach *all* college and university students, not merely the small contingent that would patronize an elective course superposed on our present curricular offerings. The most natural and expeditious way to reach all students is to introduce the new approach into present courses satisfying the science requirement.

Single-science courses lie within the present framework of curricular organization. We can operate within that framework without having to undertake the time-consuming and unnecessary task of convincing highly conservative curriculum committees of the necessity for such a change. Most faculties, especially in the sciences, see the bogey of relaxation of standards in every departure from conventional modes of instruction. We can scarcely hope to persuade our nonscience colleagues the country over of the necessity for an added required course in science appreciation soon enough to meet the present emergency, even if we had a body of trained teachers ready to take over such a course. We shall, indeed, have our hands full with the far lesser task of preparing ourselves and our science colleagues to operate on the necessary broader basis within our own respective subject areas.

The tradition of a college teacher's autonomy within his classroom protects our more conservative colleagues from pressure to change their modes of instruction. But the same tradition will permit us, and those of our colleagues who are really interested, to modify our classroom procedures to meet the urgent requirements of the times. This is an important element in the tactics and strategy of contemporary science teaching. By utilizing the single-science type of course as a vehicle for the teaching of scientific appreciation, we can surmount the double difficulty of major curriculum change and the educa-

tion of a whole new corps of teachers of science appreciation in a wide subject area. Our energies can be devoted immediately to the venture within our own classrooms. Instead of being stopped from practicing what we preach during the process of indoctrinating our colleagues, we can be providing examples of the measures we are urging, and in the meantime be making our contribution toward the solution of the major problem before us. Even if we regard the single-science course as merely a short-range preliminary solution, besides providing at least the beginnings of a liberalization of science instruction, it will increase the receptivity of the teaching profession to longer-range improvements when they shall have reached the mass-production stage.

Besides the tactical advantage that single-science courses have over multiple-science courses in the mere (though crucial) speeding up of the organization of science instruction on a wide front for the new purposes, such courses have certain inherent advantages largely independent of the time element.

1. Such courses come closely to grips with a representative portion of science, a major section of it, not merely isolated episodes selected on account of their exceptional features. This would seem to be sound pedagogy. It is certainly accepted practice in the other intellectual disciplines, such as the teaching of literature, art, and music. Nothing can ever take the place of becoming an active performer (on however small a scale) in integrating the *esprit* of a new field into one's own make-up.

2. Such courses enrich the early approach of majors and nonmajors alike. There is a double fallacy in presenting a different type of general course to prospective nonscience majors from that presented to beginning science majors. It implies, first, that scientific appreciation is not inculcated in the first-year course for prospective scientists, which if true is a pretty severe judgment on such courses. It implies, second, that scientific appreciation is imparted in the specialized advanced courses taken by science majors. Few, even of those interested in developing science appreciation, would be willing to claim that as a feature of their own advanced courses, and certainly we cannot look for it in those whose sole interest is in the production of specialists. Both our teaching colleagues and our science-major students will always look somewhat patronizing-

ly on science courses which are limited to nonscience majors. In organizing our offerings that way we create a prejudice within our own ranks which it would be wiser to avoid.

This is in addition to the practical problem which could be quite troublesome in smaller institutions, of how to induct into the major sequence the considerable proportion of prospective science majors who reach their decision for science during the first-year course. Such students are left high and dry when finishing with first-year sections that are presumably terminal, pointing away from a science major instead of toward it. Many a potential science major would probably be lost in the course of such a disjunction.

3. Such courses reach all students taking the general course in the science. If adopted by all sciences, the science requirement will then insure the highly desirable outcome that all students will have an opportunity to acquire the insight which the post-Hiroshima world is finding so urgently necessary. To confine this opportunity to students willing to elect an extra course in appreciation of science or to pilot-sections of experimental courses, which it is hoped may later be extended to all students, introduces regrettable and unnecessary delay.

4. Such a course can be adapted to all the sciences with less dislocation of the instructional program than any other means. It is true that the historical element, and hopefully a touch of the philosophical, would have to be injected into the general courses now lacking such elements. But if the teaching profession is once convinced of the necessity for broadening its approach—a task which we shall have to undertake in any event—the departures from present practice will not be as drastic and will lie far more within the field of competence of the teacher than would be the case for at least the majority of alternatives.

5. Such a course conserves the time of both student and instructor. The subject-matter material which forms the basis for "appreciation" is already developed in the normal routine of a science course—indeed more thoroughly than would be feasible or even possible in any separate "appreciation course." All that remains is to examine it from the new point of view. Experience suggests that a real re-examination of this kind, though a definite place has to be made for it, involves surprisingly little time. Any experienced teacher who has a reali-

zation of what is now at stake for our educational system and society in general can salvage such time in the way he teaches his subject.

The educational dividends of the single-science type of course, assuming always that the teacher has the vision and the intellectual breadth required, seem to be all out of proportion to the time and effort—even the considerable time and effort—that is involved in introducing the new material and point of view.

The practical teacher may request particulars on how to start the process of redesigning the general course in his science for this purpose. The first step would be for the teacher to familiarize himself with the history of his own science, usually a sadly neglected element in his preparation. It is not so much the chronology that is required, as a diligent search for the origins of the basic concepts and the technical terms. This search will carry him through the published histories of his subject and beyond them to the source books and the original papers in which the concepts and terms first appeared. He will soon find himself probing the biographies of his authors to learn, if possible, the circumstances surrounding their discoveries, the motives which actuated them and the casts of mind that determined the forms of their reports.

From comparisons of the preconceptions of various authors, and correlation of the climate of scientific opinion of their times and places, will inevitably begin to emerge some consideration of the philosophy of the science. This is a wide and a treacherous path, which the unwary may find himself treading before he even realizes it. Someone has said that everybody should know enough philosophy to enable him to keep out of it. Perhaps it would be better to say "so that he may realize its implications when he encounters it." Certainly the typical science teacher will begin at this point to feel the need of expert guidance.

Finally, the teacher will encounter and must solve the major problem of preparing the material through which his students may follow him into this new realm. This can begin with a schedule of collateral readings. But the relative unavailability of such material to students numbering in the hundreds will compel the teacher ultimately to find or to produce the text material adaptable to the new purpose. This

is, of course, no small task, but it lies within any teacher's professional competence when limited to the area of his subject-matter training. It is at this point that he will begin to realize how hopelessly handicapped he would have been, at this stage of preparation, for teaching a multiscience type of course. And it is also at this point that the wise teacher will begin to consider whether he might not to advantage profit by the professional competence of some of his colleagues familiar with sound educational practice. The report of the President's Commission on Higher Education has this to say:

To this end specialists in education and those in the liberal arts must replace their mutual skepticism with a cooperative relationship based on recognition of the fact that teachers need to know both what they are teaching and how to teach it.<sup>2</sup>

Thus do presumably well-trained teachers have to provide for themselves, at an enormous handicap an important—perhaps the most important—element in their professional preparation. This is one of the corollaries of the astonishing fact that college teaching is the only profession for which no specific preparation is required or provided.

As the President's Commission states it:

It is in the preparation of college teachers that the graduate school program is seriously inadequate . . . The more alert and thinking among college administrators have for years been asking, usually in vain, for teachers with different training and different skills . . . Without such teachers general education and liberal education of broadened scope are impossible . . . Our conception of scholarship must be enlarged to include interpretive ability as well as research, skill in synthesis as well as in analysis, achievement in teaching as well as in investigation.<sup>3</sup>

This *lacuna* in the preparation of college teachers has deprived them in some measure of the very appreciation of science, which they are now, against a serious handicap, being called upon to transmit to a generation sadly in need of it. It is the circumstance also which virtually limits all but a select few to a single subject-matter field as the vehicle for transmitting such science appreciation. We may properly look forward to a time when the college teaching profession,

<sup>2</sup>*Higher Education for American Democracy*, Vol. 1, p. 77.

<sup>3</sup>*Ibid.*, pp. 89-91.

no longer deprived of specific graduate training, can address itself without its present handicap to the broader aspects of its teaching. But we shall do well in the meantime to cut our cloth to the pattern to which we are largely limited. Therein lies the greatest and almost only promise of making immediate headway on the huge problem with which we have been caught almost unaware.

# **Science in the General Education Program at the Western Washington College of Education**

**T**HE WESTERN Washington College of Education at Bellingham, an integral part of the public school system of the state of Washington, has as its primary function the education of teachers and administrators for the elementary and junior high schools of the state. For this purpose the college offers a four-year program leading to the degree of bachelor of arts in education, in addition to which the institution, in 1947, was granted the right to institute work leading to the degree of master of education. Recently the college has supplemented the teacher education program with a four-year program in the major areas of the liberal arts leading to the degree of bachelor of arts. In a junior college division the college has for many years also met the needs of many students who have wanted two years of preprofessional training before transferring to another institution.

## **GENERAL EDUCATION PROGRAM AS A WHOLE**

An understanding of the program can best be achieved by a brief examination of its history. During the years 1945-47, the Curriculum Committee of the college after re-examining the curriculum reaffirmed the principle earlier enunciated by the faculty that the college should provide an adequate program of general education in the first two years for the rank and file of students in both the teacher education program and in the liberal arts curriculum. In the earlier revision of the curriculum in the years 1923-25 two principles guided the thinking and the actions of the faculty, and these were retained as working principles in the recent revisions. These principles

By Leona Sundquist, chairman of the science department, Western Washington College of Education.

were set forth in the catalogue of those years in the following words: "Teaching may well be considered as a particularly active and useful type of citizenship. In view of such prospective citizenship, there is need of curricula which will develop well-informed, clear-thinking, individuals who are self-disciplined, capable of forming judgments on adequate information, and having many-sided life interests. To this general training there must be added that which will fit the student for the particular teaching service in which he will engage. Any course in any curriculum may be interpreted as contributing both to the general cultural development and to the professional training of the student. A course may be planned more particularly for the one of these objectives, but will nevertheless contribute to the attainment of the other."

At the beginning of the general education program, orientation courses in Science and Civilization, History of Civilization, and General Literature were instituted. They have been maintained throughout the years with slight modifications in credits allowed, the sequence in which they occur in the student's program, and in their relationships to one another. At first they were considered three aspects of the fundamental general education background and constituted the student load in the freshman year. Because of registration difficulties and other course requirements they no longer run parallel and their sequence has changed a number of times. A certain cohesiveness between the three courses has thus unfortunately been lost. These earlier courses in the general education program of the first two years have in the course of time been augmented by others in art, music, and mathematics.

### THE SCIENCE PROGRAM OF THE COLLEGE

The science program designed for and taken by all students regardless of their curriculum or professional objective has been organized in its major aspects around the principle that a liberal education is fundamental to effective personal and social living.

#### *Functions of the science program*

On this basic conception the over-all science program was designed to perform three functions:

1. *General education.* Basic to the entire program is the provision of courses contributing to the liberal education of

all students. Courses 101, 103, and 104 (Science and Civilization) are fundamental courses designed for this specific purpose. Supplementing these, a student may elect a variety of courses from various fields of science. Selection may be made from the fields of physics, chemistry, geology, biology, human anatomy and physiology, microbiology, botany, and zoology.

For the student who is especially interested in science, provision is made for intensive work leading to majors and minors in biological and physical sciences for the degree in liberal arts.

2. *Professional teacher education.* Ample provision is made for courses in the field of science education for the elementary and junior high school classroom teacher. Besides the required work (Science 101, 103, 104, and certain professionalized subject-matter courses) in this area, a student, under guidance, may select a number of courses from the different fields of science which are especially adaptable for the needs of the classroom teacher.

Provision is made for graduate work leading to a degree of master of education in science education. This phase of the program is intended to serve the classroom teacher as well as the special student interested in becoming a consultant in science education in the public schools.

3. *Students transferring to other professional schools.* Generous provision is made for students desiring one or two years of work in the college before transferring to other types of professional schools. Students interested in such fields as engineering, medicine, dentistry, optometry, chiropody, public health, nursing, physiotherapy, veterinary science, home economics, forestry, fish and wild life, may take advantage of the basic courses provided in the various fields of science.

#### *Character of student body in relation to general education course*

The Science and Civilization course (Science 101, 103, and 104) was originally designed for teachers. Now, however, the character of the institution has changed. Many students come with other vocational motives, and some are undecided about careers and indefinite about their future. Others who come merely because they have nothing more significant or profitable to do may stay for only a year or two. Still others find their bearings and continue for the full four years either in

teacher education or the liberal arts. Another group comes with definite plans for entering professions other than teaching, such as law, journalism, business administration, engineering, medicine, dentistry, optometry, chiropody, pharmacy, forestry, fisheries, home economics, public health, and nursing. They, too, are encouraged to take courses in the general education program and many of them do, especially those interested in careers demanding very little, if any, knowledge of science. Those interested in such professions as medicine, engineering, and home economics usually do not register for the science orientation course. Although the courses are as significant and valuable in the education of a doctor and engineer as that of a teacher, many students prefer to take the traditional type of science course, such as physics, chemistry, and zoology since these subjects have greater transfer value in entering other institutions.

Sooner or later many students discover that their interests have changed, or that they have miscalculated their capacities for training in particular specialized fields, or that circumstances make it mandatory that they continue their education at the college. These students transfer to teacher education or liberal arts. This serves to indicate the need for the recognition of the value of the courses in general education for the student who plans preprofessional work in fields other than that of teaching. The transfer problem has been a nuisance in attaining the full development of the general education program of the college.

For the rank and file of students, the science orientation course (Science and Civilization) represents all the science they will ever have. It is therefore preferred that all students, irrespective of careers or curricula, select the orientation course in preference to any specific basic science course. It becomes imperative then that the course be effective in implementing the attainment of its objectives.

#### SCIENCE AND CIVILIZATION 101, 103, 104

The description of the science program and types of students served indicates that the science orientation course is required of all liberal arts and teacher education students, and that it is recommended for all other students.

This general course is *not intended to be a survey course* in science. It does cut across the various subject-matter fields of

science but the intent is not to survey these fields. Emphasis is placed upon the orientation of the student to the problems of everyday life and to the facts, concepts, principles, and techniques of science which can serve as tools to develop more efficient ways of thinking and living. This involves the development of a definite scientific attitude, actually a means of thinking, resulting in an understanding of the effects of science not only upon personal well-being, but upon our entire complex society. In this course, then, the relationship of the subject matter to the student is of primary importance.

The following description of objectives and content are taken from the present school catalogue and represents what is actually being attempted in the work of the course.

*101, 103, 104. Science and Civilization.* 5 credits each. These courses in general education are designed to furnish the student with a science background for an understanding of the part played by science in evolving our complex modern society.

The objectives of the courses may be stated as follows: (1) to give an intelligent understanding of the known universe which exists and the origin and development of life on the earth; (2) to develop a realization of the importance of the role that the scientific attitude of mind and the scientific method of thinking and investigating have played in the affairs of mankind and to indicate the need for cultivating and developing these characteristics and habits and utilizing them in the solution of our personal and social problems; (3) to provide the intellectual stimulus which comes from analyzing the great discoveries of the master scientists, their devotion to truth, their capacity for unremitting labor, their unselfish spirit of service, and their cooperation in their work; (4) to establish a sympathetic and cooperative attitude toward all sincere work in pure and applied science; and (5) to aid in interpreting intelligently man's place in nature and in evolving a sane and wholesome philosophy of life.

Illustrative material is freely used and appropriate experimental work is introduced wherever practicable.

*101. Physical Science.* 5 credits. A course designed to give an understanding of the contributions of the physical sciences in the growth and development of modern society.

The content of the course is briefly outlined as follows:

1. Science in the modern world
2. The scientific attitude and the scientific method of thinking and investigating
3. Man's changing concepts of the material universe and of the inorganic basis of life:
  - (a) The earth in relation to the universe
  - (b) Earth-making forces and processes; their importance and effect upon man as a part of nature
  - (c) The physical-chemical aspects of matter and energy, their interrelationships and man's utilization of them

*103, 104. Biological Science.* 5 credits each. A course designed to give the student a realization of the contributions which the biological sciences have made toward the understanding of the nature and development of life, the characteristics of the human body, its health and hygiene, and interrelationships between organisms and the interactions between organisms and environment. *The human organism in the world of life is the focal point of the course.*

The content of the courses is briefly outlined as follows:

1. Biological science and the modern world
2. The scientific attitude of mind and the scientific method of thinking and investigating as applied to the problems of man as a living organism
3. Man's changing conceptions of the world of life:
  - (a) Nature and distinctive characteristics of life
  - (b) Cellular basis of life. The physical and chemical basis of protoplasm
  - (c) The development and behavior of tissue and organ systems with particular reference to the human body
  - (d) The problems involved in human health and hygiene
  - (e) Variety and interrelationships among living organisms
  - (f) The interactions between organisms and their environment, stressing the use of this knowledge as applied to man

(g) The principles of genetics and their application to such phenomena as adaptation and evolution; emphasis is placed on their importance to man and his problems.

#### NATURE OF INSTRUCTION

There is always a discrepancy between theory and practice. A conception of a course and its function is one thing; its practical operation is another. It may be well to indicate some of the problems involved in the instructional aspects of the course.

Each class meets five days a week. Three single-hour periods are devoted to lecture-discussion and two double periods are utilized for laboratory-demonstration work. Ordinary laboratory rooms, accommodating a maximum of 45 students, have been used for class work, an arrangement which has made possible flexibility in the use of lecture, laboratory, and demonstration. The rooms have been supplied with tables, chairs, a large lecture-work table, sinks, hot and cold water, and outlets for gas and electricity, and they can be darkened for projection of slides, films, and pictures, and for experiments involving a dark room.

Unfortunately the enrollment has recently increased to the extent that the classes are too large for the available rooms. Larger groups tend to reduce discussion which is vital in an exchange of ideas and the clarification of thinking. Under these circumstances class meetings tend to degenerate into straight lecturing which is, after all, a teacher and not a student activity. The smaller the class, the more varied the activities, the more satisfactory the results.

Group demonstrations and experiments of various types are freely used in both lecture and laboratory periods. Charts, models, specimens, slides, films, pictures are considered indispensable and field trips in small groups and by the class as a whole are conducted whenever feasible. Whenever possible individual laboratory work is organized in order to provide opportunity for the student to experience the feeling of discovering, and the strength of arriving at conclusions from observed facts.

Examples will illustrate the use of materials and activities in instruction:

1. The following materials and activities are provided to offer opportunities for the student to realize that man and all life are dependent upon certain conditions determined by the relationship existing in the distribution and relative motion of heavenly bodies in space. This also involves concepts of vastness of space and man's present ideas regarding the nature of the universe.

a. Construction and use of charts and models to indicate relative sizes and distances. An effective demonstration conducted outdoors is one involving relative sizes and distances of heavenly bodies on the same scale.

b. Demonstrations of relative movements of heavenly bodies which produce the phenomena of day and night, seasonal change, apparent movements of planets, phases of the moon, and other heavenly bodies. A planetarium may be used, but simple things like balls, lights, globes, projectors, and one's own self are better.

c. Field trips at night for the study of relative positions and movements of the main constellations, planets, and moon involve observations from a fixed location throughout certain hours at night and certain nights throughout the quarter. A small telescope is used in observing the moon and planets.

d. Films and pictures are used wherever feasible.

2. The following materials and activities provide opportunities for the student to arrive at such conclusions that the earth is very old, that changes have occurred and are occurring, that forms of life have changed throughout geological time, that man can reconstruct the past history of the earth and can usefully employ the knowledge not only in an academic but also in an economic sense.

a. Films, slides, pictures, charts, models, and maps are freely employed.

b. Rocks and minerals are studied not only as individual specimens, but in series order of rate of cooling and crystallization, and in series order of deposition in water.

c. Field trips are taken in small groups and by the class as a whole to local deposits of sedimentary rocks, fossil formations, and glacial debris.

d. Local events regarding river erosion, sedimentation, and the need for control and conservation are used to advantage.

An important objective of the course is to acquaint the student with the way in which the scientific method has modified the world in which he lives. The past fifty years of research in the structure of matter is a timely illustration of this point. The student is led to understand that yesterday's unfamiliar research is today's common knowledge. Moreover, he comes more fully to appreciate the cooperative nature of science when he sees that the discovery of isotopes by an American, of the neutron by an Englishman, and of nuclear fission by a German have created problems of great significance to every person living on this earth.

1. The following types of materials and activities acquaint the student with the techniques and equipment used in research:

- a. The assembling of apparatus to evacuate a tube and the observation of the gaseous discharge makes more meaningful the importance of Crooke's cathode rays. The physical properties of a stream of electrons have more meaning to the person who has observed the results produced by these electrons.
- b. The experience of having "heard" the effect of bringing a uranium salt near a Geiger detector which is connected to an amplifier and a loud speaker makes more meaningful the phenomenon of invisible radioactivity.
- c. Atom charts and models are utilized to acquaint the student with the changing ideas in this area.
- d. Films, such as the March of Time film on *Atomic Energy*, give further acquaintance with the people who have carried on atomic research, and supplement the voluminous reading on this subject.
- e. The discussions arising from these demonstrations and expressions help to focus attention upon the implications of atomic energy for contemporary civilization.

2. The relationship of structures and functions of the body and the need for their intelligent care are brought out by the following means:

- a. Frog and cat dissections are used in the study of the relationship of structures and systems. The specimens are prepared beforehand, making the lesson a semidemonstration and laboratory activity. Charts and models of the frog and

the human female torso and male pelvis are also used in this connection.

*b.* Laboratory provisions are made for the study of the blood, the cells, and the tissues of the body. This involves the use of the microscope, the preparation of their own slides as far as tissues permit, and the use of microprojectors in the study of these structures. These projectors are very effective in the demonstration of blood circulation, corpuscles, the difference in the flow of blood through arteries, veins, and capillaries, and live spermatozoa from the testes of the frog.

*c.* Demonstrations such as that of osmosis and digestion of starch are used to illustrate processes.

*d.* Certain laboratory activities have been devised to indicate techniques used in the science of medicine, such as the preparation and sterilization of culture media. After the preparation of the media and sterilization of petri-dishes the student is asked to contaminate them in various ways, such as placing the thumb on the media, coughing into the petri-dish, running a pencil or comb over the media, and subjecting the media to dish water. The growths are then observed and studied under the microscope. Other laboratory activities include blood pressure tests taken under varying degrees of physical activity, blood counts, and urinalysis tests.

*e.* Many specimens, models, excellent charts, and demonstrations are also used in the study of structures and functions of the systems of the body.

3. The following materials and activities develop concepts regarding the origin and evolution of life, adaptations, survival, and extinction.

*a.* Models, phylogenetic display of animals, charts, and films are used to illustrate the progressive development of organs and organ systems in animals.

*b.* Selected slides and models of larvae and key primitive living forms are studied and compared with fossil forms.

*c.* At a local salt water bay students study living animals representative of all phyla. The vast number and variety of animals are noted and compared to land forms, posing the problem as to the conditions conducive to the probable origin of life. Observations are directed toward variations within different members of the same phylum living in different physical environments. Changes in the conditions

in the bay and the associated changes in numbers and distributions of types of animals are pointed out. These conditions suggest factors operating on a larger scale in the modification and extinctions of many forms of life.

### EXAMINATIONS

In treating examinations one must consider their function. Examinations during the quarter are considered one of the instruments of instruction and are largely devised for this purpose. Examinations at the end of the quarter serve two purposes: they determine a grade for the student but they also evaluate the outcomes of the course in attaining the objectives. New types of examinations are required since traditional subject-matter tests are not adequate. Great ingenuity must be exercised to provide opportunities for the student to face problem-type situations which demand exercise in organization, induction, deduction, determination of conclusions, analysis of subject matter, and critical thinking.

Laboratory and demonstration work is frequently checked by means of a "practical" test. By use of a microprojector in a darkened room students are asked to identify materials on a slide or to give short concise answers to questions asked regarding the function of structures, their origins, and relationships as the case may be.

### STRENGTHS AND WEAKNESSES

Any study of courses for general education must consider the fact that the teacher is the major factor in success or failure. Irrespective of the degrees and preparation a teacher may have, the following characteristics loom high in importance. First and foremost, the teacher must be convinced of the value of and be aware of the function of general courses; a science teacher must be convinced of the significance, importance, and function of the science courses in general education. A teacher must recognize the objectives and content of the science course in terms of their contribution to the growth of young people toward understanding themselves and their environment and toward assuming responsibilities in a dynamic society.

Much of the success of the science orientation course stems from the fact that the science teachers are in agreement with the fundamental philosophy and objectives underlying the

program. This agreement is more than mere verbalism; it takes concrete form in the nature and method of instruction, in the efforts made to analyze the results, in the willingness to modify methods and procedures, and in the cooperative spirit of work which is imperative.

One of our problems has been the securing of properly trained personnel. Since we are a small college, a faculty person is called upon to teach classes in the traditional science courses, such as chemistry, physics, or geology, as well as classes in science orientation. In this respect, there has been difficulty in obtaining the proper balance in the training of instructors and in meeting the needs of the institution.

Inadequate preparation in diversified fields of science as well as a lack of generous background in the social sciences and the humanities is a weakness in the preparation of teachers of science for general education. Breadth of training as well as thoroughness is desirable. The instructor must be able to do an adequate job in the general course in terms of the broad aspects of science, and also in the areas of specialization. The lack expresses itself, too often, in an inability to integrate the experiences in the separate areas into a meaningful whole for the student. The narrow and intensive training so characteristic of many people in science is inadequate for general education. It might be suggested that more consideration should be given in our universities to the preparation of teachers for general education. Doctoral degrees should be given and recognized for broad thorough training in several science fields rather than for the narrow intensive work which is generally characteristic of the work in graduate schools.

#### OUTLINE OF COURSE IN PHYSICAL SCIENCE (101)

##### I. The Universe Around Us

1. What is science?
  - (a) The characteristics of the scientific attitude
  - (b) The aim of science
  - (c) The method of operation which science has found successful in the solution of problems
2. History and introduction to astronomy
  - (a) The Ptolemaic universe
  - (b) The Copernican universe
3. The solar system
  - (a) A description of the members of the solar system, the relationships which exist among them, and the methods by which these facts are determined

4. The sun
  - (a) What is known about the sun and the methods by which these facts are determined

5. Our galaxy
  - (a) The size and shape of the galaxy
  - (b) The members of the galaxy, their relationships, and their evolution

6. Beyond our galaxy
  - (a) What?

## II. The Structure of Matter

1. Early concepts

- (a) What is matter?
  - (b) Early theories regarding the structure of matter

2. Progress toward modern concepts

- (a) Dalton's atomic theory
  - (b) The periodic classification of the elements
  - (c) Cathode rays and x-rays
  - (d) Radioactivity
  - (e) Further research leading to modern concepts

3. The planetary electrons

- (a) Quantum theory
  - (b) Bohr theory
  - (c) Atomic structure and molecular structure
  - (d) Ionic theory
  - (e) Chemical changes illustrated in living organisms and in industry as sources of materials and energy

4. The atomic nucleus

- (a) Structure of the nucleus
  - (b) Isotopes
  - (c) Binding forces
  - (d) Atomic fusion and atomic fission

5. Use and control of atomic energy and related phenomena

- (a) Present and probable uses
  - (b) Plans for the control of atomic nuclear reactions
  - (c) Implications of nuclear physics for modern society

## III. The Earth's Crust and the Forces Which Change the Earth's Crust

1. The earth's crust

- (a) The facts concerning the earth's crust
  - (b) The materials which make up the earth's crust

2. The forces of gradation

3. The forces of vulcanism and diastrophism

4. The rhythm of gradation and diastrophism

5. The record to be read from the rocks

## OUTLINE OF COURSE IN BIOLOGICAL SCIENCE (103)

### I. Science and life

What are some of the historical ideas of life and livingness? Where are we today in our development of concepts of life and livingness? How does science deal with the problems connected with an investiga-

tion of life and its characteristics? Vitalism and mechanism: two points of view, one method for both

## II. Life and livingness

Living vs. nonliving

Energy systems and changes: photosynthesis, dehydration synthesis, hydrolysis, and oxidation. Interrelationships between plants and animals in this energy pattern: carbon cycle, parasitism, decay, decomposition, nitrogen cycle

The material basis of life: protoplasm, proteins, fats and carbohydrates, colloids and catalysis

## III. The human organism and its optimum maintenance

The cell as the unit of structure and function

The cells organized into tissues, organs, and systems. Structures and their relationships. Function and malfunction of the tissues, organs, and systems

Diseases: their cause and prevention.

# OUTLINE OF COURSE IN BIOLOGICAL SCIENCE (104)

## I. Knowledge and classification

Operation of the scientific method in general biology

## II. The animal kingdom

Basis of classification: the historical setting

Comparison of type forms in each phylum

Embryological origins and development of systems

Comparative study of systems and their functions

Adaptations, parasitism, symbiosis, etc.

Trends in development from an evolutionary point of view

## III. The plant kingdom

Basis of classification: the historical setting

Comparison of type forms in each plant group

Discovering the combination of structures and characteristics which have proven successful in plant evolution

## IV. Genetics

How have organisms come to be the way they are?

Nature of chromosomes, genes, characteristics

Different types of inheritance

Mutations

Variations

Adaptations

Application to human problems

Heredity, training, environment

Inheritance of special abilities, etc.

Heredity, health, disease, longevity

Heredity, race, population trends

Genetics and its implications in evolution

- V. Evolution—descent with change
  - Historical setting
  - Evidences of evolution
  - Evolutionary story of representative plants and animals and of man
  - Problems of interpretation
- VI. Ecological aspects of present distribution of plants, animals, and man
  - Man and his environment—resources
  - Man and his future

## The Comprehensive Science Courses at the University of Florida

THE GENERAL education program at the University of Florida is conducted under the administration of the University College. All freshmen and sophomores—now numbering over five thousand—are enrolled in this college. Each student, on the average, devotes over half his time during these two years to study in seven comprehensive courses, one of which is in the physical sciences and one in biological science. All seven courses have been integral parts of the general education program since the establishment of the University College (initially called the General College) in 1935. Each course has experienced some degree of change, from slight to profound. Probably the physical science course has been the most difficult to construct.

### THE PHYSICAL SCIENCE COURSE

During the twelve-year history of the physical science course, the staff and the administration have been unable to solve two distinct, though closely interdependent, types of problems: (1) those dealing with subject matter and teaching technique and (2) those dealing with administration. Because of the inherent complexity of the subject and the specialized, though varied, training of teaching personnel, these problems are probably encountered to a greater or lesser degree wherever this type of course is taught.

The solution of problems stemming from the nature of subject matter and the type of teaching techniques employed lies mainly with the staff. These problems include (*a*) establishing

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This article was written as a cooperative undertaking by four of the staff members of the physical science course, L. W. Gaddum, W. W. Ehrmann, R. A. Edwards, and H. L. Knowles, and by C. Francis Byers, chairman of biology. The article was read, and certain minor alterations suggested, by Winston W. Little, dean of the University College, University of Florida.

objectives, (b) selecting appropriate subject matter, (c) employing adequate teaching techniques to carry out the objectives, (d) designing a method of evaluation for student and staff achievement.

The solution of problems dealing with administration lies mainly with the administrative officers of the school. These problems include (a) inducing capable physical scientists to divert an appreciable part of their originality and ingenuity from the development of conventional science courses and research to the development of a comprehensive course in general education, (b) protecting staff members against loss of prestige resulting from reduced participation in their fields of specialization, (c) inducing specialists to overcome the apathy or contempt they might feel toward fields other than their own, and to enter conscientiously into the serious study of whatever fields might justifiably be included in the comprehensive course, (d) acquiring adequate demonstration and laboratory equipment and classroom and laboratory space, and (e) promoting staff members, both financially and professionally, on an equitable basis with staff members in the conventional science courses.

### *Three phases of general education*

The organization and development of a general education course in the physical sciences at the University of Florida have passed through three phases: (1) a period of reconnaissance during which the course was essentially a survey course; (2) a period of development during which the staff attempted to develop an integrated study of socially significant physical factors of modern civilization; and (3) the present period, in which the course is again essentially a survey of the physical sciences. The turbulent period of reconnaissance need not be discussed at great length since the "alarums and excursions" of that period were primarily those typical of any pioneer period. It is necessary, however, to describe in some detail the second and third phases of development, during which most of the problems listed above were encountered. The sole reason for recounting these experiences is that those who are organizing programs of general education may profit not only from the achievements but also from the errors of the past.

The principal achievement of the reconnaissance period was

the realization by the staff that the early survey course in certain respects was very unsatisfactory. The course consisted of a series of separate pieces of the various physical sciences, related only by the word "science." The contribution to the student seemed to be superficial and could be summarized in the phrase, "Isn't science grand!" The principal achievement of the student apparently consisted of a regurgitation parrot-fashion of poorly digested information which he was unable to use to interpret the world around him. Because in the survey course the number of subjects covered was great and because the material was covered somewhat hastily, and hence superficially, the course was seemingly producing aspirants for a radio "quiz" program rather than cultivated minds. One of the original goals of the general education program was to encourage students to use the library by using a required text augmented by optional parallel reading assignments. In the physical science course this optimistic hope was not attained. As should have been expected, the use of the library by freshmen with crowded schedules was practically nil.

Another unsatisfactory feature of the early survey course was the lack of any real coherence of subject matter. Since each instructor taught his section of students throughout the entire course and since he exercised complete freedom in selecting the topics or points he wished to emphasize, no real unity existed either within each section—except insofar as the instructor's individual bias or ingenuity produced integration—or among the sections taught by one man as compared to those taught by others. Instead of one course with a significant unifying theme, there were as many different courses as there were instructors. Within limits, individual variations in teaching are inevitable and even desirable, but the lack of unity which prevailed during the reconnaissance period was excessive.

### *The integrated course*

To remedy these defects, the staff discarded the survey and organized an entirely new program, the main theme of which was *integration*. This word in itself, however, does not by any means describe all the staff sought to achieve; nor does it indicate how carefully the course was to be organized with respect to subject matter and teaching technique to achieve even a

small measure of integration *in the student's own mind*. In consequence of this new endeavor it was hoped that the student would acquire a really comprehensive understanding of an integrated body of scientific facts and principles and a meaningful appreciation of the relationship between this knowledge and himself as an individual and as a member of human society. The way in which the attainment of these rather high-sounding goals was sought can be understood best by reviewing the course and the way in which the material was taught.

In order to eliminate the disconnected nature of the survey course, the staff organized the subject matter not in terms of physics, chemistry, geology, geography, and astronomy, but rather in terms of a study of the physical environment of the human race and the utilization of that physical environment by man. The number of individual topics studied during the entire year was too great to enumerate here, but illustrations of the way in which these topics were studied will be described later.

During the first semester, the various factors contributing to the entire physical environment and to the different habitats on earth were developed in a logical and interrelated sequence. Some of the major subjects, in the order in which they were considered, were: the sun—latitude and longitude; the solar system; the ecliptic plane, the zodiacal and other constellations; insolation and atmospheric temperature; atmospheric pressure, winds, and ocean currents; humidity and precipitation; storms and weather; climatic regions of the earth; vegetation cover of the earth; processes which form the land; world distribution of land forms; the nature of matter and energy as the fundamental elements of the physical environment; rocks and the structure of the earth; and major soil types of the world. The time allotted to each topic varied greatly. One lesson, for example, was devoted to a study of the ecliptic plane and constellations, four to world climatic regions, and eighteen to the nature of matter and energy.

The main theme of the second semester was the study of the nature and utilization of material and energy resources. The major topics in the order, in which they were studied, were: basis of transformations of matter; basis of transformations of energy; the nature of resources; mineral products and animal and plant products; power production and utilization

of power. The course ended with a comprehensive summary of regions of the earth and of man's adaptation to his environment.

To attain real integration of subject matter, it was planned to develop a working knowledge of the facts and principles involved and, wherever pertinent, to demonstrate the significant relationship of the topic under study to other topics. To cite only one illustration, the resource coal is used as a case in point. By the end of the course the student had a clear knowledge of the geologic origin of coal; some fundamental chemical and physical characteristics of coal in combustion, in power production, and in the manufacture of steel and of coal-tar products; its world distribution, particularly with reference to iron ore deposits and the development of industrial centers; the role of coal as the major source of power in modern industry and transportation; and its enormous strategic importance in peace and war.

In order to systematize the study of this rather vast array of knowledge for both students and instructors, two study guides were written.<sup>1</sup> These study guides were not textbooks in the conventional sense of the word—that is, they were not composed entirely of descriptive material—but were rather guides to the thinking of instructors and students. It was presumed that the student would learn the *factual material* of the course by reading the assigned references in standard texts and other related books—an ample number of which were placed in the University College reading room in the main library. The *interpretation* and *integration* of facts was the function of the study guide. Since real thought usually, if not always, arises from problems or questions, it was felt that interpretation and integration of factual material would be best attained by posing carefully planned questions. Hence the bulk of the study guide consisted of questions and problems.

Each study guide contained forty-five units, three units for each week of the semester. Each unit consisted of a single topic (or set of related topics), a statement of essential facts

<sup>1</sup>L. W. Gaddum, D. F. Williams, W. W. Ehrmann, and R. R. Mulligan, *Man's Physical Environment* (439 pages, Gainesville, 1940) was the study guide for the first semester; and W. W. Ehrmann and D. F. Williams, *Energy and Material Resources* (378 pages, Gainesville, 1941) for second semester. R. A. Edwards also assisted in a revision of the first text; and D. F. Williams wrote a revised edition of the second.

and principles, references to required readings, illustrative examples, and material for discussion. The illustrative examples—generally five to each unit—were in the form of questions which could either be answered by the student unassisted, provided he had studied both the unit and the references, or were answered and carefully explained for the student. The material for discussion was also in the form of questions—ten to fifteen in each unit. A few were on the subject of the current assignment; the others covered material previously studied in the course. The review questions were distributed in such a way that over a period of a few units the student reviewed all the material previously studied, thus achieving some integration of larger blocks of material.

#### *Objectives of the integrated course*

The study guides were planned to be the heart of the course. The four main objectives of the study guides, and hence of the course, were (1) to achieve a reasonable degree of unity with respect to content and instructional technique, (2) to induce the student to use the library, (3) to force the student to use his reasoning ability and ingenuity, rather than to rely solely upon the accumulation of disconnected facts, and (4) to present an integrated picture of man's physical environment and of his adjustments to this environment.

The accomplishment of the first objective—unity and coherence—was to some extent inherent in the use of the study guide, for it indicated to student and instructor alike the line of reasoning and various relationships which should be emphasized. Thus all instructors were guided and even constrained to follow the same pattern of emphasis, a pattern which, it should be pointed out, was established by the staff itself rather than by dictatorial edict.

The attainment of the second objective—use of the library—also met with some success. To learn the basic facts and principles of the course, the student necessarily had to use the library since the study guide contained almost no factual material. In fact, it could be truly said that the library was the textbook of the course. Under these circumstances it was not surprising that the librarian's records showed greater use of the physical science references than the references of any other comprehensive course.

To induce students to use reasoning processes rather than to emphasize mere memory or blind use of formulas—the third objective of the course—it was necessary to prepare a definitely planned set of questions. As a result of this experience the authors wish to describe a few characteristics which, in their opinion, such thought questions should possess. In the first place, they should contain superfluous information so that the path of reasoning is not too clearly charted. Most of the problems of daily life do not come to us with all superfluous information pared away to reveal the skeleton of the reasoning which leads to the solution. To force the student to "hunt for clues," therefore, useless information was deliberately incorporated in these questions even at the cost of increasing the time necessary to read them. In the second place, careful reasoning of a "common sense" variety should be emphasized rather than the meticulous precision of the academician. Occasions certainly do exist where meticulous reasoning or calculation is needed; occasions also exist, however, where meticulous precision in reasoning degenerates into pedantry. Sometimes in precision machine work, measurements accurate to  $1/1000$  of an inch might be necessary; only a fool, however, would plan an automobile trip with such precision. For certain purposes an accurate topographical map is desirable, but only meager geographical information is necessary to know that Kansas contains no real mountains. All too often the student's ability to make "common-sense" inferences is paralyzed by his notion (too well founded) that in the classroom one substitutes razor-edge discrimination for "common sense." In the third place, such questions should not be solvable by pure memory alone. Clearly, memory has its legitimate function, but it should not crowd out thought processes. Accordingly, the thought questions were designed with these ends in mind.

An integrated picture of man's physical environment and of his adjustment to this environment—the fourth objective of the course—was made possible by the logical arrangement of topics and by the interrelation of these topics as already mentioned. True insight into these matters was insured by incorporating the concept of integration of facts and principles into what were called, for want of a more descriptive term, "thought questions." For illustration, consider the following example:

Taken from the narrative of an exploring expedition:

"About one hour after sunset, we pitched camp. Already darkness had fallen, and by lantern-light the job was not easy, even though the sky was clear and rich with stars. Due north on our meridian stood Jupiter, shining brightly among the stars of Gemini, while to the west and south of our zenith the sky was brilliant with the bright stars of Orion and the Big Dog. A warm wind, fetid with the smell of dead things, came from a thicket of acacia trees to our south, blowing across the tall grass which fringed our camp-site. We could hear the snarling . . ."

About when and where might the above have occurred?

- (1) the llanos of Venezuela, about 5:00 P.M., October 5.
- (2) the Russian Ukraine, about 5:00 P.M., April 30.
- (3) central Kenya, about 7:00 P.M., March 20.
- (4) southern Uruguay, about 6:00 P.M., January 6.
- (5) southern Bechuanaland, about 8:00 P.M., July 15.

To evaluate the question properly, the reader should put himself in the student's place, answering the question and grading himself +1 if correct,  $-\frac{1}{4}$  if incorrect, and 0 if unanswered.

Although the problem looks difficult—and, of course, it was to one who had not studied the material—the average student could solve it with relative ease. The reasoning involved is simple. By a previous study of a simplified constellation map and descriptive reference, the student had learned that Gemini is near the meridian at midnight at winter solstice (actually it is centered on the meridian at 1:00 A.M. on December 21) and being on the plane of the ecliptic is also centered around  $23\frac{1}{2}^{\circ}$  north of the celestial equator. In each succeeding month the meridian crossing occurs two hours earlier. Hence, for each of the five possible answers the meridian transit occurs (1) on October 5 at about 6 A.M., (2) on April 30 at about 5 P.M., (3) on March 20 at about 7 P.M., (4) on January 6 shortly before midnight, and (5) shortly before noon. Choices (1), (4), and (5) are, therefore, eliminated by these time considerations. Only choices (2) and (3) need to be considered further. Choice (2) is eliminated for two reasons: one, since the Russian Ukraine is north of the Tropic of Cancer, Gemini would appear to the south; and two, at 5 P.M. on April 30, it would still be daylight in the Russian Ukraine and, of course, no stars could be seen at that time. Choice (3) is obviously the correct answer since it fulfills all the stipulated conditions: Gemini is on the meridian at 7 P.M., March 20; in Kenya, at this time, it is just after dark; at this

time Gemini would appear in the northern sky as viewed from Kenya. The information on Jupiter is superfluous.

In addition to the thought questions, the study guides contained, of course, a large number of orthodox questions which required for their answer merely the knowledge of one fact, of one set of facts, or the correct application of a scientific equation. Wherever possible, both types of questions—those requiring only memory and those involving reasoning processes—were stated as real situations or potentially real situations rather than as detached, hypothetical phenomena which exist *in vacuo*. Many examples were stated in such a way that the student had to draw upon his knowledge of many facts and principles and to synthesize them into a coordinated solution. The staff actually composed several thousand questions which were kept in a central file on five- by eight-inch cards and which were catalogued by topics and combinations of topics. Several hundreds of these were analyses of passages or figures taken from novels, poems, explorers' accounts, newspapers, government documents, and other sources. The application of these techniques, as well as others already discussed, created a really meaningful relationship between the student's individual experiences and the subject matter under study. The following four examples, as well as the one already given, illustrate in a very small way the manner in which it was hoped to achieve the desired goals.

#### *The goals achieved by questions*

One of the questions in Unit One of the study guide for the first semester, the very first lesson in the course, was:

A ship captain, taking observations from the bridge of his ship, observed the sun at an altitude of  $16^{\circ}$  when it crossed his meridian to the south of his zenith. The Nautical Almanac gives the sun's declination at that instant as  $17^{\circ}\text{S}$ . In which one of the following regions might the ship have been at the time of the above observation?

(1) Mediterranean Sea (2) Baltic Sea (3) Caribbean Sea (4) Arabian Sea (5) Red Sea.

The student had learned by a study of the references and of the essential facts and principles in Unit One the meaning of and relationship existing between altitude, zenith distance, declination, the yearly apparent movement of the sun, and latitude—as well as such “tool” information as the size of the

nautical mile and the number of nautical miles in each degree of latitude difference. The student knew, therefore, that if the altitude of the sun were  $16^{\circ}$ , its zenith distance was  $74^{\circ}$  ( $90^{\circ} - 16^{\circ}$ ). Since the sun was due south, the ship was  $74^{\circ}$  of latitude north of the position where the sun was overhead which according to the Nautical Almanac was at  $17^{\circ}\text{S}$  latitude. The ship must have been at  $57^{\circ}\text{N}$  latitude. If the student did not know the approximate location of the five seas given as possible answers, he consulted a world map in one of the reference texts or atlases. From this information he learned that the only possible choice of the five was the Baltic Sea. It must be emphasized that the student was not expected to memorize the exact location by latitude and longitude of the five seas. He was expected, however, to learn their relative location with reference to other major geographic features. Concerning the Baltic Sea, he should have noted that it is located not far south of the Arctic Circle; is bounded by the Scandinavian Peninsula on the west, Germany on the south, the Baltic states (U.S.S.R.) on the east, and the Gulf of Bothnia on the north; and empties eventually into the North Sea. In a similar manner he learned equally significant facts about the other seas listed as possible answers.

Even subjects normally considered purely scientific and dissociated from the everyday life of the student were readily adapted to thought-type questions. For example, in the study of elements during the third month of the first semester, the student was given a sketch diagram of the periodic table which had spaces for all elements. About two-thirds of the spaces throughout the table contained only the symbols of the elements which occupied those places. If the total number of the remaining empty spaces scattered throughout the periodic table were thirty-three in number, the blank spaces were arbitrarily numbered in sequence from one to thirty-three. With only this information the student was able to answer the following question:

A certain element has the following properties: In the solid state, the element is hard and brittle and is not a good conductor of electricity. With hydrogen, the element forms a compound in which two hydrogen atoms are combined with one atom of the element; with oxygen, a number of compounds are possible, in one of which three oxygen atoms are combined with one atom of the element. The atom of the element is heavier than the neon atom but is lighter than the iron

atom. The position of the element in the periodic table (as shown in the diagram given to the student) is

(1) 11      (2) 2      (3) 7      (4) 4      (5) 5  
(in this particular problem the 11 was occupying the position of arsenic, 2 silicon, 7 potassium, 4 sulphur, and 5 chlorine.) The correct answer is choice number (4), element arbitrarily marked 4.

By this problem and many others of the same type the student gained a real familiarity with the periodic chart and its characteristics. By this technique he also learned quite indirectly and almost without conscious effort, the names and characteristics of all the common elements.

Another type of problem which was used to excellent advantage was called the "Region A" problem. (The region could, of course, be called "B," "C," or "X," "Y," "Z.") The problem consisted of the description of an actual region on the earth's surface in terms of temperature, rainfall, winds, land forms, climatic type, soil type, vegetation, type of land utilization, natural resources, industries, trade, transportation systems, or other criteria, or a combination of two or more of these characteristics. The answer choices to each problem were selected in such a way that only one would fit the conditions given in the description of the region. The following problem containing several different descriptive elements is an example of a relatively easy problem but one which took the average student a long time to read:

Region B is a long, narrow valley averaging about twenty-fives miles in width and four hundred miles in length. To the west is a low coastal range and to the east a very high mountain range. The average monthly precipitation ranges from almost 0.0 inch in January to over 3.0 inches in July and the temperature from 68°F in January to 48°F in July. The central valley or trough has been filled by silt and gravel from the mountains and has formed a layer of rich soil which in places is more than three hundred feet deep. The perpetual snows of the mountains to the east are the source of a usually adequate supply of muddy irrigation water which nourishes the soil and supplements the light winter rains. The principal crops are grapes, citrus fruits, olives, nuts, figs, wheat, barley, and alfalfa, supplemented by corn, apples, peaches, and potatoes. Most of the agricultural produce, with the exception of some wheat and wine, is consumed at home. Although the valley supports a dense or moderately dense population, the adjacent territory to the east is practically uninhabited. Region B is:

(1) Adelaide District of Australia    (2) Mesopotamia  
(3) the Sacramento Valley    (4) Po Valley, Italy  
(5) Central Chile

Another illustration of the type of question which used sources from real life follows:

The following excerpt is taken from testimony given by J. B. Gordon, representing the Bureau of Raw Materials for American Vegetable Oils and Fats Industries, before the Ways and Means Committee of the House of Representatives in January, 1934. Mr. Gordon is testifying in opposition to an excise tax on imported oils, fats, and oilseeds.

"*Mr. Gordon.* . . . No 200,000,000 pounds either of low-grade nor of high-grade or of any other kind of cottonseed oil goes into the soap industry. It is almost not used there at all. And that is the case even though frequently it can be bought at a lower price than the price at which the commonly used soap oils can be purchased. Cottonseed oil is not suited for the manufacture of soap. Its chemical make-up is such that it is not a good soap oil.

*Mr. Treadway.* Why is it not suitable for soap?

*Mr. Gordon.* Cottonseed oil contains 42 percent, which is a very high percentage, of linoleic [Mr. Gordon obviously refers to "linoleic acid"] acid which, when the oil is used in making soap, oxidizes and makes the soap rancid. For instance, if you wash clothes . . . you would give the material that you washed, if you used soap made from the cottonseed oil, a rancid bad smell. . . That is what you get in the clothes when you try to wash them with soap produced from cottonseed oil.

\* \* \* \*

*Mr. Gordon.* . . . The greater portion of power laundry soap is made from tallow, and coconut oil or one of these imported oils, palm oil, with the addition of coconut oil. Some of them are made entirely of tallow or palm oil. In the households, where the housewife launders her own clothes, these soaps are very apt to be made of palm oil and coconut oil or olive oil, because they have quicker sudsing and rinsing properties."

Careful analysis of Mr. Gordon's testimony involves the consideration of certain implications and neglected aspects of the question at hand:

Which one of the following lists all, and only, those of the statements below which are correct?

(1) a      (2) b      (3) c      (4) a,b      (5) b,c

(a) Mr. Gordon's testimony implies that an excise tax on imported fats would lower the price of cottonseed oil in the United States by stopping the importation of coconut oil, at least so long as the Philippine Islands are possessions of the United States.

(b) Mr. Gordon's argument that cottonseed oil is *not* commonly used in the soap industry while coconut oil is widely used, is inconsistent because coconut oil contains a greater proportion of linoleic acid than does cottonseed oil.

(c) Mr. Gordon's testimony implies (perhaps unintentionally) that an excise tax would not aid the cottonseed oil industry so far as coconut oil is concerned, because an excise tax would not apply to coconut

oil shipped from the Philippine Islands while they are possessions of the United States.

Which one of the following lists all, and only, those of the statements below which are correct?

(1) a (2) b (3) c (4) a,b (5) a,c

(a) Mr. Gordon's testimony neglects the question whether hydrogenated cottonseed oil might not compete with coconut oil if an excise tax were placed on the latter.

(b) Hydrogenated cottonseed oil can be used in the soap industry as well as tallow, hence the cottonseed oil industry might receive some benefit from an excise tax on imported tallow, since over 40,000,000 pounds of tallow were imported in 1934.

(c) Since hydrogenation of cottonseed oil would increase the proportion of linoleic acid, the hydrogenated oil would be even less suited to soap manufacture than is the original cottonseed oil, according to Mr. Gordon.

During the course the student had access to adequate information which enabled him to understand such significant relationships between utilization of resources and social and political problems.

These five illustrations give only a small degree of insight into the scope of what was attempted in two semesters. Each student solved over two thousand questions in the course of one year; fourteen hundred came from the study guides, seven or eight hundred from the biweekly tests which the students were allowed to keep, and a variable number from the comprehensive examinations of previous years which students could purchase from the bookstore. By constantly working with and solving such a large number of really integrated and comprehensive questions, the student gained a mature appreciation of the material which would have been impossible with less intensive methods.

During those years when the study guides were used, the course consisted of four classroom hours a week: three discussion periods and one lecture-demonstration. The discussion periods were devoted to instructor-student participation in discussing and answering the questions in the study guide. The lecture-demonstrations were primarily demonstrations with the aid of slides, motion pictures, scientific apparatus, or large wall charts and maps illustrating facts and principles outlined in the study guide. Whenever a lecture with visual aids was given, it was interpretative, or concerned materials not covered in the reading, although related to the topic. A mere restatement of the required reading, on the one hand, and pure "hum-

"buggery" on the other, were assiduously avoided. Every effort was made to inspire serious interest on the part of the student rather than to lure by mere entertainment.

*Problems connected with the integrated course*

In the endeavor to establish the integrated program, many serious problems arose. The most serious of these were administrative in nature and were largely beyond the control of the individual members of the staff.

The most fundamental problem was that of inducing capable scientists to contribute actively to the new program. This situation produced what is still an unsolved dilemma. Active contribution to such a course necessarily demands a decrease in the time devoted to research and to other professional activities. Yet professional prestige rests largely upon research, publications, and professional consultation in one's field of specialization. What rewards could be offered to a capable man to persuade him to leave the traditional path to certain professional prestige in order to enter into a new and uncharted field? Young Ph.D.'s with considerable promise do not wish to teach full time in a nonspecialized course for fear of becoming isolated from their chosen field. If they can be induced to work part time in the comprehensive field, they want—with complete justification—real guarantees that they will be able to maintain their professional contacts through teaching and research in their own field. Older men who have attained some professional prestige do not forsake their old hunting grounds for adventures into uncharted fields in spite of the supposed enchantment that should accompany such a move. Yet these capable specialists who must also possess the desire to teach young people, most of whom will never take another course in the scientist's own field, are needed if the general education courses are to be other than amateurish.

Due to the independent administration of the various colleges of the University of Florida, staff members of the University College could not be guaranteed the right to teach a course in their own fields of specialization in the appropriate college of the upper division. Many permanent members of the comprehensive course have taught in the upper division, but they have been allowed to do so only by very informal agree-

ment which carried no guarantee of permanence. While this kind of arrangement was satisfactory in some cases, it was not in others. The greatest handicap was that prospective new members from elsewhere could not be guaranteed opportunity to teach advanced courses. A corollary with respect to the colleges of the upper division in their relationship to the University College was equally true. Several faculty members from the upper division gave generously in time and effort to the comprehensive course. As time passed, they gained the impression that they were not being compensated either financially or professionally for their work in the general education program. In fact they seemed to have suffered a distinct setback in their special fields and, as a result, they felt constrained to return entirely to their fields of specialization.

The belief among the faculty that specialization was more profitable than participation in general education was confirmed by the information called for on the university professional service reports which were submitted by all faculty members to the administration. These reports all too clearly emphasized extrateaching activities—research, publications, participation in off-campus professional and other similar activities—as opposed to teaching problems on the campus. The faculty drew the obvious inference, whether correct or not, that this relative emphasis represented the desires of administrative officials.

Other problems, although not particularly serious in themselves, intensified an already difficult situation. If the student made a good placement grade on the physical science entrance test, he was given the privilege of substituting the introductory course of his science major. The right to exercise this privilege, although made available only to a minority, had the effect of labeling the comprehensive course as preliminary and of branding it as unnecessary except for inferior minds.

These problems were not successfully solved, and this fact, along with the advent of the war with its train of new problems, made impossible the continuation of the integrated course. Accordingly, the staff felt that they should discontinue the attempt and should reinaugurate a survey course using a standard text in the field. The difficulties encountered by the attempted integrated course were far more serious than those in the survey course. The integrated course suffered severely

from criticism by many administrative officials, faculty colleagues, and certain types of students. These criticisms arose out of the fact that these people did not understand what was being attempted, because they either were not in a position to know, or would not take time to find out. At present, with the survey course, with a few minor exceptions, adverse criticism is practically nonexistent.

#### *Return to the survey course*

The present survey course, running through two semesters, deals mainly with the principles of physics, chemistry, meteorology, geology, and astronomy. So far as possible the material is presented nontechnically and with some emphasis on applications in modern life, in two demonstration-lectures and one discussion period each week. In general, the procedures are much the same as in the usual survey course, and the problems of the course are mainly those which arise from the over-crowding of universities throughout the country.

The traditional nature of the material taught in the present survey course is familiar to administrative officials, faculty members, and students. Moreover, the physical sciences are today in the public eye. Consequently, a survey of physics, chemistry, and so forth needs no apology or explanation. On the contrary, the integrated course suffered from the fact that, so far as was known, this type of course had never been satisfactorily worked out in other places. What was more important than the mere criticism was the fact that such criticism was clearly reflected in the administrative difficulties which were experienced. Also, the qualifications of staff members are not so rigorous for the survey course as for the integrated course; it is much less difficult to maintain a sufficiently capable staff at present than when the integrated course was attempted. Since all material for the integrated course was necessarily written by the staff, research by staff members suffered and their professional service reports were blank. On the other hand, many adequate texts are available for the survey course and hence more time is available to staff members for research. On the whole, the administrative problems seem easier in the case of the survey than for the integrated course.

There seems to prevail throughout educational circles the thought (with which we agree) that general education courses

in the physical sciences fall short of being completely satisfactory. So far as our experience is concerned, it does not appear that these shortcoming or failings are inherent in the problem of general education. In the interest of this movement it is to be hoped that the necessary remedial action will be taken.

#### THE COMPREHENSIVE BIOLOGICAL SCIENCE COURSE

The course in biological science is a companion course to the one dealing with physical science and many of the problems and objectives of the two are similar. However, the nature of the subject matter, the homogeneity of the area covered, and the history of the development of biological teaching have made our problems less difficult than those encountered in the physical sciences.

Pioneer work in the field of general education was done for the biologist by A. Franklin Shull of the University of Michigan. Dr. Shull's insistence that elementary biology should be taught as a series of integrated concepts or principles and not as a study of individual representative animals paved the way for the establishment, years later, of comprehensive courses in biology for general education.

The course at the University of Florida was strongly influenced, in its beginnings, by the Shull tradition. It was necessary to extend the principles idea, however, to cover a wider field and to encompass the factual material that we felt the student needed to support the pertinent ideas and concepts that we wished him to take away from the course. But, as many of the desirable possibilities in such a program had been discovered by our predecessors, we were able to start out with a reasonably well-integrated course.

Our initial efforts provided the student with a syllabus and study guide which was simply an outline of the topics to be considered and a series of questions designed to direct his attention to factual material supplied by assigned readings in textbooks and library reference books. The course was then, and still is, supplemented by demonstration material—specimens, lantern slides, movies, museum displays. The work covered two semesters, gave eight hours' credit, and terminated with a six-hour comprehensive objective examination.

In the twelve years since we began, a number of changes have been made in materials and procedure. Today we are more

convinced than ever that it is practicable to offer a single-year course which presents biological principles and stresses an appreciation of the data and the reasoning on which such principles are based. Such a course, we believe, constitutes a definite contribution to the student's knowledge of himself and of the world in which he lives.

We found the syllabus and assigned readings unsatisfactory chiefly because it was difficult to write examination questions that would be fair to all students in all sections of the course unless they had had a common core of knowledge and a common experience in class. With hundreds of students, many instructors, and a long list of reference works this was not possible. The only solution that suggested itself was to write our own book, which we did.<sup>2</sup> The success of this book has renewed our confidence in the soundness of our assumptions.

We strive to present biological science not as a technical elementary course suitable for students intending to major in the field, nor as a survey of botany and zoology, but rather as a comprehensive treatment of the living world, "accurate and detailed when necessary," so that an educated man will no longer feel that the subject matter and concepts of the life sciences are a baffling, mysterious, or esoteric set of problems. Intelligent living in the modern complex world requires that a university graduate should know about Darwin as well as about Shakespeare, should know as much about scientific principles as about ethical or political ones.

Our course treats of the nature of life and a knowledge of its processes by presenting the living world from four viewpoints:

1. *The isolated individual organism*

Under this heading we discuss the cell; nature of protoplasm; the structure and functioning of the human body machine; the structure and functioning of plants in comparison and contrast; and close with a brief summary of the varied patterns of animal and plant life (not a taxonomic survey).

2. *The organism as a link in a sequence of generations*

Here a new group of problems is encountered—the origin of the individual; the significance of death; sex and reproduction; variation; and the individual's role as a contributor of inherited factors to the next generation.

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<sup>2</sup>J. S. Rogers, T. H. Hubbell, and C. Francis Byers, *Man and the Biological World* (New York: McGraw-Hill Book Co., 1943).

*3. The organism as a product of evolution*

Here we present the concept of organic evolution as opposed to that of special creation; the contributions of Darwin, Lamarck, De Vries; the evidence for evolution as derived from modern organisms; the geological history of life; the evolution of the primates and man; races of modern man.

*4. The organism as a unit in a social-economic complex*

This section of the course deals in general with the problems of ecology—the energy-cycle; the nature of the physical environment; the biotic environment; parasitism and disease; food-chains; biotic communities and plant succession.

Throughout the course we stress scientific method, the value of experimentation, deductive as well as inductive reasoning; and application of methods and materials to human problems.

Although many of the initial problems in achieving the objectives and viewpoints of the course have been met, that does not mean that all obstacles have been overcome. At present, the most serious difficulties may be listed under four headings: (1) adequate examinations to measure the achievement of the objectives attempted in class; (2) a program and set of criteria for selecting and training teachers in biology for general education; (3) curriculum adjustments between our course and other university units offering instruction in the biological sciences; (4) adjustments necessary to meet the demands of preprofessional programs, especially in medicine and dentistry.

1. *Adequate examinations.* Because of the large number of students taking this course (1,800-2,000) it is necessary to give machine-graded, objective examinations. It is easier to construct items for these examinations which test for facts only. Such questions as the following were used almost exclusively in the beginning.

104-110. Use the key list below to answer the following items.

**Key List**

1. Anapsida
2. Diapsida
3. Parapsida
4. Synapsida
5. Synapsida  
5. Synaptosauria

(   ) 104. Reptiles with a pair of lateral temporal openings in the skull belong to which subclass?  
(   ) 105. Reptiles with no temporal openings in the skull belong to which subclass?  
(   ) 106. The archosaurs belong to which subclass?  
(   ) 107. The snakes belong to which subclass?

- (   ) 108. The pterosaurs belong to which subclass?
- (   ) 109. The crocodiles belong to which subclass?
- (   ) 110. The corylosaurs belong to which subclass?

This type of question places emphasis on fact learning and rather detailed fact at that. Consequently we have experienced great difficulty in keeping the student, frequently the instructor as well, from becoming lost in a morass of unrelated details. Some details are necessary to give the student an appreciation of, and practice in, the methods of science so that in the care of his health, in the conduct of his life, in his thinking concerning such things as heredity, evolution, religion, and so on he may proceed with the very "confidence mingled with caution" that an educated man must have. But the details are means to this end and not an end in themselves.

Since the machine-graded, objective examinations makes us stress facts when the course is designed to stress principles, questions of the following type are now employed:

80-83. These questions are based on the following key list.

#### Key List

- (1) factor in x chromosome
- (2) factor in y chromosome
- (3) factor in an autosome but character requires presence of a male hormone to appear
- (4) factor in x chromosome but shows up only under influence of male hormone
- (5) factor in x chromosome as recessive lethal

*Directions:* Select the one of the above conditions which best accounts for each of the situations described below.

- (   ) 80. An inherited human character is found only in certain males; all affected individuals have affected fathers.
- (   ) 81. An inherited human character is found only in certain males, but a study of many pedigrees shows that it is equally likely to be inherited through the mother or through the father.
- (   ) 82. A human character is found in both man and woman, but is more common in man than in woman; affected fathers rarely have affected sons; affected sons are produced when both parents are phenotypically normal; affected daughters never appear unless the father is affected.
- (   ) 83. A human quality results in the still-berth of male babies. The living brothers of such babies never transmit the tendency, but it is transmitted by some of the living sisters.

2. *Teacher training.* The postwar expansion of the university with increased student enrollment has necessitated the

addition of new staff members. These had to be trained in service. In general education broadness of viewpoint, sympathetic understanding, tolerance, a wealth of experience in outside fields, liberalism, and a bit of the missionary spirit are matters to be considered. We must expect our faculty to possess those same values that we tell our students they will acquire from a general education program. General education has broken with tradition not only in its re-evaluation of subject matter, but in the qualities that it expects in its teachers as well. We recognize, of course, that there is danger here. Superficiality with a pleasing personality may be selected in place of solid worth. Adequately trained teachers is still one of our most pressing problems.

3. *Curriculum adjustments.* Some of the courses in the general education program are mainly used as parts of the core curriculum; others may serve as prerequisite courses for advanced study in their respective areas. The course in biological science has the dual responsibility of meeting the requirements of both general education and of the upper-division units. This presents a difficulty. Even more disturbing are the problems caused by upper-division units which by-pass this course and substitute one of their own limited, technical, and traditional courses in its place, thus defeating the purpose of the general education program.

4. *Preprofessional training.* The problems here are closely allied to those indicated under "curriculum adjustments" but somewhat simpler. The chief one has come about through the necessity of having the Biological Science course serve as the "general laboratory biology" requirement for entrance to medical and dental schools. The department of biology of the upper division has helped with this problem by offering a laboratory course without lecture, based on, and running parallel to, our course. Through this device we can offer our course either with or without laboratory and so do not have to modify it in such a manner as to loose its value in a program of general education.

## The Correlated Science Units at Northwestern University

FOUR YEARS ago the liberal arts faculty of Northwestern University adopted a new curriculum leading to the degree of bachelor of arts. The objective of the program as stated in the bulletin issued to prospective students reads: "The dominating purpose in setting up the new curriculum is a desire to unify the body of knowledge believed essential to a liberal education. The sixteen units of study are carefully planned to incorporate discipline in each of the major divisions of learning and to secure a balance of values among these fields."

The program recognizes the problem facing the student when he attempts to select an organized set of courses for a broad cultural education from the several hundred specialized departmental offerings. The program "seeks to correct the grosser evils of the elective system. It assumes that it is the responsibility of the faculty to define what constitutes a liberal education, though some freedom of choice is allowed the student after he has acquired the basic philosophies and essential facts of the primary disciplines. Whatever the student's choice, however, the program is so arranged that the units will supplement each other and contribute, as related parts, to a whole. The guiding principle in planning the content and relationship of courses has been the intellectual welfare of the student, with a view to his ultimate worth as a man and a citizen."

Several of these units, particularly 3, 4, and 8, call on the resources of more than one department and require the services of several specialists. This paper will be concerned primarily with the Science Unit (3) of the program.

The university bulletin introduced this unit of the program to prospective students in the following statements: "Man

By C. J. Overbeck, professor of physics, and R. M. Garrels, professor of geology, Northwestern University.

## THE NEW CURRICULUM

[ COMPREHENSIVE EXAMINATION ]

## FOURTH YEAR

TUTORIAL CORRELATIVE READING	WORK IN A FIELD OF SPECIAL INTEREST	WORK IN A FIELD OF SPECIAL INTEREST	SPECIAL PROBLEM OR AREA STUDY
13	14	15	16

## THIRD YEAR

MUSIC  GRAPHIC AND PLASTIC ARTS  PHILOSOPHY	IN A FIELD OF SPECIAL INTEREST  WORK	A UNIT ELECTED OUTSIDE THE FIELD OF SPECIAL INTEREST	A SOCIAL SCIENCE; OR PHILOSOPHY
9	10	11	12

## SECOND YEAR

LITERATURE	A MODERN FOREIGN OR A CLASSICAL LANGUAGE <i>(Continued)</i>	A PHYSICAL OR BIOLOGICAL SCIENCE; OR MATHEMATICS	MODERN SOCIETY
5	6	7	8

## FIRST YEAR

THE USE OF ENGLISH	A MODERN FOREIGN OR A CLASSICAL LANGUAGE  THE NATURE OF LANGUAGE	AN INTRODUCTION TO SCIENCE  MATHEMATICS	THE BASES OF SOCIAL LIFE
1	2	3	4

lives in a physical world and is himself a physical being. Underlying all understanding of the physical universe is the knowledge of inorganic matter and of energy and of that system of measurements whereby all things are comprehended. Allied in basic importance is the knowledge of life, its forms, and its relation to the physical earth. Man is a living being and cannot know himself apart from other forms of life and from the earth, their common habitation."

"One of the essentials of a liberal education is a thorough understanding of the scientific method. Another is an appreciation of the mutual dependence of the fields into which scientific study is of necessity divided. A third is a clear understanding of the relationship between the study of scientific phenomena in the classroom and the world of nature. Completing the unit begun by instruction in mathematics, six months of study in the first year are devoted to mastering these essentials. Materials from the major fields of science are presented in lectures, demonstrations, and, when appropriate, laboratory exercises. The method of presentation employed is such as to acquaint the student with the important role of science in the modern world and to make him familiar with the nature of each of the sciences so that he can make a more intelligent choice of the particular science he will study in the second year and in which, perhaps, he may desire to do special study later."

Since its initiation there have been periodic revisions to introduce those ideas or plans which experience with the course indicated advisable. The original objectives of the unit and the teaching plan have been quite consistently preserved. The change has been primarily one of relative emphasis of the several objectives.

The course is a two-quarter course. Three lecture-demonstration classes and two discussion sessions are held each week, in addition to which the student has five laboratory problems each quarter. When appropriate, field trips are used as a laboratory session. Up to this time it has been a required unit open only to freshmen in the bachelor of arts program. Its prerequisite is the mathematics quarter, and students in their sophomore year go directly into one of the eight regular college science or mathematics classes.

Since the unit is distinctly interdepartmental, the selection of material to be incorporated and the sequence and method of presentation fell logically on a committee representing the several departments concerned. Thus the preliminary plans for the course were prepared by a committee consisting of one member from the staff of each of the following departments: astronomy, botany, chemistry, geography, geology, physics, and zoology.

Various plans for the course were suggested and discussed at length. There was early agreement that it must not be a short survey of the several sciences, but that it must emphasize the unitary nature of science and its mode of development. A selection of the basic laws of nature was made, laws which the educated man should not only know but understand. This understanding in nearly all cases required the assimilation of materials from all the classical branches of science.

After the general plan of operation was finished and the materials of the course selected, the details were worked out by three members of the committee, one representing each of the three science divisions: the physical sciences, the biological sciences, and the earth sciences. This committee of three completed the lecture plans and made assignments in the distribution of teaching load for the original committee. The assigned lectures were then prepared for presentation. They were first given to an audience of colleagues prior to presentation to students. This was a worthwhile procedure. The correlation between the several lectures was greatly improved, and duplicated material eliminated. Many weak details also were brought to light—excessive number of names of scientists introduced, the use of units of measurement not previously defined, and general rough spots of presentation. No other method would have served so successfully to knit together the parts of this course.

Presentation of a particular lecture is now assigned to that staff member deemed best qualified for the job. Occasionally a guest lecturer is used. Even though each lecture is a unit in itself, the sequence of lectures ties together. It is the job of the lecturer to present his topic, making full use of previous lectures, in such a manner that the men following may use the new material as additional background. At all times each lecture includes the appropriate information from all science

departments, stressing the interrelationships existing between them. The laws of nature are treated as a unit rather than departmental areas. For example, the lecture on energy involves several sciences:

Astronomy—the dynamic characteristic of all bodies of the universe; the radiant energy of the sun as our principal energy source.

Botany—the restoration of our energy supply through photosynthesis.

Chemistry—release of heat energy by chemical changes.

Geography—effect of earth topography on the availability of several forms of energy.

Geology—the accumulation of available energy in geological deposits.

Physics—the laws of thermodynamics, energy transfer, and conservation.

Zoology—animals as heat engines.

It should be remembered that different goals are set for the several lectures. Some are broad and stress interdependence of the several sciences, some treat a single idea with considerable depth, others emphasize the historical development as illustrative of the scientific method, while still others point out particularly the sociological implications.

The yearly re-evaluation of the course and the subsequent revision has trended toward greater restriction of the number of ideas presented and has placed an added stress on the development of those ideas to greater depth as illustrative of the scientific method. There is interest, of course, in giving the student a knowledge of those laws of the physical universe which an educated person should possess, but understanding is emphasized, and not the accumulation of factual information.

The following are typical lecture assignments:

## WINTER QUARTER LECTURE SCHEDULE (1947-48)

Lecture No.	Date 1948	Title	Lecturer	General Topic
1	Jan. 5	Measurement	Krogdahl	Measurement
2	7	States of Matter	Klotz	
3	9	Classification of Matter I	Klotz	
4	12	Classification of Matter II	Klotz	Matter and Energy
5	14	Energy	Overbeck	
6	16	Heat	Overbeck	
7	19	Sound and Wave Motion	Overbeck	Matter and Energy
8	21	Light	Overbeck	
9	23	Uses of Spectra	Krogdahl	
10	26	Earth Form, Location and Projection	Powers	Organization of Matter
11	28	Our Solar System	Krogdahl	
12	30	Stars and Galaxies	Krogdahl	
13	Feb. 2	Laws of Motion I	Krogdahl	Interactions of Matter and Energy
14	4	Laws of Motion II	Krogdahl	
15	6	Chemical Change—Types	Klotz	
16	9	Chemical Change — Rate	Klotz	Interactions of Matter and Energy
17	11	Nature of an Earth Science	Garrels	
18	13	Energy Cycles in the Earth	Garrels	
19	16	Cycles of Matter Transfer in Earth	Garrels	Nature of Matter and Energy
20	18	Matter and Energy through Time on Earth	Garrels	
21	20	Earth's Surface Features	Powers	
22	23	Physics of the Atmosphere	Powers	Nature of Matter and Energy
23	25	Weather	Powers	
24	27	What is Electricity?	Overbeck	
25	Mar. 1	Electrons at Work	Overbeck	The Scientific Method
26	3	Radioactivity	Klotz	
27	5	Atomic Structure	Klotz	
28	8	Electromagnetic Spectrum	Overbeck	The Scientific Method
29	10	Nuclear Energy	Overbeck	
30	12	Nature of the Scientific Method	Klotz	

## SPRING QUARTER LECTURE SCHEDULE (1946-47 REVISED)

Lecture No.	Title	Lecturer	General Topic
31	Solutions and Ions	Klotz	Nature of Matter
32	Colloids	Klotz	and Energy (Continued from W. Q.)
33	Organic Chemistry	Summerbell	
34	Chemical Reactions in Biological Systems	Klotz	
35	The Nature of Life	Bingham	
36	The Role of the Nervous System in Coordination	Bingham	
37	The Relation of Food to Life	Bingham	Organization
38	The Role of Photosynthesis in the Organic World	Bingham	and Activities
39	Source and Utilization of Foods	Bingham	of Protoplasm
40	Respiration and Related Processes	Bingham	
41	The Internal Environment of Man	Bingham	
42	The Chemical Coordination of Life Processes	Bingham	
43	The Life Cycles and Organization of the Simplest Organisms	Doty	
44	Sexual Reproduction at a Cellular Level	Doty	
45	Reproduction at the Elementary Organ Level	Doty	
46	Reproduction at the Advanced Organ Level	Doty	Reproduction and Heredity
47	The Human Vertebrate	Doty	
48	Variations between Parent and Offspring	Doty	
49	Chromosomes and Heredity	Doty	
50	The Nature of the Gene	Doty	
51	The Diversity of Living Things	Balamuth	
52	World Climates	Powers	
53	Some Evidences of Evolution from Living Things	Balamuth	Organic Evolution
54	Interrelationship of Biological and Physical Change through Time	Garrels	
55	The Mechanism of Organic Evolution	Balamuth	
56	General Interrelations among Organisms and Environment	Balamuth	
57	Some Biological Aspects of Disease	Balamuth	Interrelations among Organisms
58	Man's Place in the Natural World	Balamuth	

It will be noted that in nearly all cases the individual lectures are units of larger ideas, and an attempt is made to produce a logical sequence of topics. Some additional understanding of this sequence may be gained from the introductory remarks which accompany the lecture schedule and lecture outline given to students.

#### INTRODUCTORY REMARKS

##### *Winter Quarter*

The ultimate goal of science is a unified theory and system of laws which will correlate phenomena in all fields of experience. Such a project can be only an ideal, however, for no man can assimilate the factual information in all the diverse branches of science. In surveying the field, therefore, we shall limit ourselves at any given time to only one important class of phenomena. Nevertheless, we shall not divide our discussions into the rigid classical categories—astronomy, botany, chemistry, geography, geology, physics, zoology—for these divisions are really quite arbitrary and fail to emphasize the unitary nature of science. Since each of these specific disciplines contributes to a full understanding of any given field of facts and events, we shall need to assimilate materials from all of the classical branches of science.

Scientists generally are engaged in two activities: (1) the observation and description of materials and phenomena; (2) the formulation of general laws to correlate these observations. A science is not fully developed, however, until its studies are quantitative; and quantitative expression depends on an understanding of the process of measurement. Our course opens, therefore, with a consideration of the nature of the measurement process. Examples of familiar concepts, such as time and distance, are used, and emphasis is put on the progressive increase in precision of definition and measurement as any field of science develops.

The earliest man who showed any curiosity about his surroundings was undoubtedly first impressed by the many types of matter in nature. As time went on man began to exhibit interest also in the nature of less tangible phenomena which we recognize today as manifestations of energy. Therefore we too shall consider initially the different types of matter and various manifestations of energy.

There are so many individual facts and phenomena in these two fields that it is necessary to group them into various categories and to correlate them by means of general statements called "scientific laws." We shall describe some of these laws. We shall describe also the thought processes by which the intellectual giants of science were led to the development of the fundamental concepts and laws which describe natural phenomena. Then we shall try to integrate different concepts and experimental laws by setting up a theory to account for them. The theory in turn will suggest new experiments which will lead to new classifications of natural phenomena, to new laws, and then to revised theories. This process of continuous flux is a distinguishing characteristic of the scientific approach.

Having considered various manifestations of matter and energy, we shall proceed to a discussion of their large-scale organization in the universe—the earth, the solar system, the galactic and extragalactic systems. Here again we shall emphasize the continuous interplay between theory and observation.

As physical science has developed it has become increasingly evident that matter and energy are not independent phenomena but are very closely associated. We shall continue, therefore, with a consideration of various manifestations of these interactions, first in astronomical phenomena, second in chemical changes and third in geological transformations. The geological transformations are excellent examples of the meeting of various branches of science—astronomy, chemistry, physics—in a field in which they have been frequently excluded when a narrow scientific point of view has been adopted.

We shall close the work of the first quarter with a consideration of the present concepts of the *nature* of matter and energy. Theory and experiment are so closely intertwined—each influencing the course which the other follows—that we must describe new phenomena such as radioactivity and electromagnetic radiation. These experimental phenomena are the foundations of current theories of the nature of matter and energy. Nevertheless, we must recognize that the firmly established current theories will lead to new experiments which will extend our horizons of experience, so that we shall be forced to continue to modify our concept of the universe, as well as our conduct as social beings. A close examination of the scientific method whereby these advances have been made is thus in order.

#### Spring Quarter

The work of the spring quarter will proceed to a further exploration of present concepts regarding the nature of matter and energy. The explorations will continue with a study of solutions and ions, colloids and organic chemistry, all of which are significant in the succeeding investigations regarding the organization and activities of living matter.

The remaining work of the course is concerned with life and so may be named biology. It is no accident that the study of biology comes at the end of the Introduction to Science course, nor does the study of biology at this time in any way violate the integral nature of the course. Because of the dynamic aspects of life it has been impossible to extend the fronts of science in this area as far as has been done in the several physical sciences. So often when one investigates the activities of living creatures, it is necessary to destroy the life, and dead protoplasm is not the same as living protoplasm. Furthermore, all living things vary in so many different ways that it is difficult to establish adequate controls for experiments. Besides, the materials which compose living organisms come from the physical surroundings and return to them. Many of the reactions which occur within living things also take place in the laboratory. Much that is known about the processes that take place in living material has been discovered by the use of the same methods so productive when applied to inanimate materials. Theory and experiment continue to be closely intertwined. Though much of biology is necessarily descriptive, experimental

biology is dependent upon the researches in physics and in chemistry. Many of the concepts we shall deal with in our study of life are dependent upon those we have developed in this course up to this time.

Our study of biology will begin with a consideration of the organization and activities characteristic of all protoplasm. We shall proceed to find out how living things reproduce themselves; how hereditary traits are passed on from generation to generation. We shall then consider the evidence that life has become more diversified and complex through time, and attempt to find an acceptable explanation to account for this evolution. Finally we shall investigate the various interrelations among different living organisms and between them and their physical environment. We shall be especially concerned with man's place in the world.

Throughout the spring quarter we shall follow the same procedures as have been followed during the winter quarter. It is our hope that as a result of your studies you will become convinced of the unity of science and develop adequate techniques to continue to grow in your understanding of science and in your ability to use it with increasing effectiveness in your personal and social living.

Nearly all the lectures are of the demonstration type. Care is exercised to select equipment which is simple, direct, and quite visible to all the students. In a few cases data are taken and treated mathematically to clinch the idea being presented. Each lecture is carefully planned so that a general informal presentation is maintained. Those teaching methods which actively encourage student participation in the lecture-demonstration are employed. Slides and motion pictures are used to supplement the work when the material does not lend itself to lecture table demonstration.

In addition to reading assignments from a selected text and from library references, the student is given a set of questions to guide his work for each lecture. These questions, usually six to ten an assignment, stress the major ideas of the lecture and serve as a guide in the discussion classes. The students are encouraged to set the pace in the discussions. A considerable portion of the work there is an interplay of student contributions with the instructor giving general guidance and drawing conclusions if necessary.

The following are four sets of such questions taken from the current list. A study of these questions will indicate the trend of thinking for these particular lectures.

#### Lecture 3—Classification of Matter

1. In what particulars did the ancient and alchemical classifications of matter fail as scientific theories?

2. In what ways were the theories of the alchemists a stimulus to scientific development?
3. What was the contribution of the Iatrochemists to scientific thought?
4. What was Boyle's major contribution to the concept of element?
5. Make a diagrammatic representation of the modern method of classification of matter. Define each class in terms of the experimental characteristics by which it is recognized.
6. Account for each of the classes of matter in terms of atomic and molecular theory.
7. Outline each of two theoretical accounts of the process of burning of tin.
8. Describe the crucial experiments which form the basis of the acceptance of Lavoisier's theory of burning.

#### Lecture 6—Heat

1. The statement was made that Galileo's simple, calibrated thermometer "inaugurated the scientific study of heat." Elaborate.
2. Describe the two experiments which overthrew the caloric theory of heat. Why was a new theory necessary?
3. Distinguish between heat and temperature.
4. List the changes in physical properties of materials which might be used to measure temperature.
5. The three methods of heat transfer are conduction, convection, and radiation. Describe the mechanism of each.
6. A flame is placed under a vessel containing 100 gms. of ice at -40° and the heating process is continued until all the water is vaporized. How would a thermometer placed in the H<sub>2</sub>O during this process behave? How many calories of heat are required?

Specific heat ice = .5

Specific heat water = 1

Heat fusion = 80 cal/gm

Heat vaporization = 540 cal/gm

7. What is meant by "absolute zero"?

#### Lecture 17—Nature of an Earth Science

1. Draw a diagram illustrating the interrelationships of the "basic sciences" and the earth sciences.
2. What is meant by the sampling problem in earth science? Is this problem critical in the "basic sciences"? Do you think it would be in the quantitative aspects of sociology?
3. What methods of ascertaining events which have occurred in the prehistoric past can you enumerate? What is the basic nature of the proof of the assumption of Uniformitarianism?
4. List at least two methods based on observations of present earth features which have been developed to gain an insight into past conditions.

#### Lecture 55—Mechanism of Organic Evolution

1. Is organic evolution a fact or a theory, in your opinion? Does acceptance of the reality of evolution imply acceptance of a given mechanism whereby evolution may have occurred? Explain.

2. What was the value of Lamarck's work? Is the worth of a scientist gauged by the degree of acceptance of his theories in later generations? Give some analogous cases from physical science.
3. What were some of the factors accounting for the great impression made by Charles Darwin's work?
4. What were some of the similarities and differences between the theories of Lamarck and Charles Darwin?
5. In what sense can De Vries be said to demonstrate a link between genetics and evolution?
6. Indicate some of the basic problems in this field which remain unanswered.
7. It is commonly stated today that "Darwinism is discredited." From your lectures, readings, and discussions try to obtain some general evaluation of this view.

Initially the laboratory work consisted of one representative experiment performed in the laboratories of each of the associated sciences and sponsored by the department. It was soon recognized that this placed an unusual load on the departments and disrupted their regular work. Since the choice of experiment depended on the availability of apparatus and the time on the departmental schedule, there was little chance of correlating the laboratory experience with the rest of the course. Two years ago, therefore, the staff requested funds to start an integrated laboratory. This laboratory is now in its second year of operation and still in process of development.

The criteria used for selecting experiments is essentially the same as used for other parts of the course. The following topics are included in the current list.

1. Units and methods of measurement (includes method of triangulation)
2. Study of gas laws
3. Production and analysis of spectra
4. Meteorology.
5. Electrical circuits
6. Chemical identification of unknowns
7. Digestion of starches and proteins
8. Study of cells, tissues, and organs
9. Basal metabolism

In addition to field trips, there are continuous experiments in operation, especially in the spring quarter. One of these shows the effect of diets on animals while another usually run is on plant propagation.

As is true for all courses, a grade must be reported as an estimate of the student's work. In this course a ten-minute quiz is given each week. Contrary to our expectations, we find that the majority of the students welcome this series of short examinations because it places less emphasis on the midterm and final examination scores. The computed grade also carries a score representing the instructor's judgment of the student from class contributions.

These students in their sophomore year elect a regular college science (Unit 7). Since two quarters are devoted to Unit 3 whereas twenty-one quarters are devoted to the first college courses in the seven science divisions, exclusive of mathematics, the average time spent in this unit on the subject matter of any one of these sciences, provided no difference of emphasis or overlapping of material is considered, is less than 10 percent. Thus the student should not be expected to be ready for the second course in the departments. He should, however, be able to do better work in his selected science because of the added background.

To date there is available the record of seven quarters of work of these students in their elected conventional departmental science classes (Unit 7). These classes are composed of both bachelor of arts and bachelor of science students, approximately half of whom are freshmen who have had no other college science. The balance of the class are sophomore or upperclass bachelor of science students who have already had one year of a departmental science. On a scale in which A and B grades are considered "above average work," 61 percent of the bachelor of arts students to date have received A and B grades. During the seven quarters, however, there was a wide variation from quarter to quarter, which probably represents in part a similar fluctuation for the entire class and in part perhaps it is a result of the smallness of the group of bachelor of arts students. In the quarter in which the scores were lowest, 43 percent of the bachelor of arts group had A and B grades, and in the quarter with highest grades 81 percent of the bachelor of arts students made A and B grades in their sophomore elected science.

In the quarter of poorest record, this group approximated the class average. In the other quarters studied, they rank up to 20 percent higher than average. It should be remembered

that the work of Units 3 and 7 does not stress identical features.

The lecture, discussion, and laboratory work is planned to operate as a unit emphasizing insofar as possible the same interests at the same time. Since the pace and the sequence of the course is set by the lectures, it is necessary, for proper integration of lectures and conduct of discussion classes, that the entire staff of the quarter attend all the lectures. This is vital to the success of the course.

In addition to the staff meetings each year for re-evaluation and revision of the course, there is a weekly one-hour staff meeting to discuss current problems and procedures. These sessions involve not only subject matter but frequently a discussion of the mode of presentation. There has been excellent give-and-take in these sessions—a recognition that the group is interested in the improvement of the course and that the remarks do not reflect personal or petty features.

It may truthfully be said that this close operation of the course has produced a fine spirit of companionship in the group. It is not necessary to belabor the point that the critical spotlight of an audience including colleagues, followed by a review session, is a tremendous stimulus toward doing the best possible job. Perhaps we should be bold enough to say that a portion of the cost of the program is returned in the general improvement of the teaching effectiveness of the group, not only in this course but in their other classes. The cost referred to is the teaching credit time granted to the staff for lecture attendance—full credit in the first year, and half credit in succeeding years.

The time given by an instructor to this work is normally from one-third to one-half of a full load while participating in the course. The subject matter divides naturally into the physical sciences and the biological sciences. Nearly all the instructors serve for only one of the two quarters. Thus by far the major part of their work for the year remains in their departments. This means a greater staff shift, but in our opinion is a better plan than having a few special B.A. instructors serving most of their time in the one course. Men qualified and willing to accept work on the latter plan are difficult to find.

The course, however, has suffered by a much too frequent change of departmental representatives. Both the course and its instructors must remain dynamic, but too great a shift of instructors tends to loss of continuity and duplication of effort. This is one of the present problems. One of the rules of procedure is a system of "understudy." The department contemplating a shift of its representative on the lecture staff provides at least two men to the staff in the year preceding the shift. The understudy, who attends all lectures in the year, becomes acquainted with the details and sequence and can thus assume the lectures in the following year, maintaining the continuity and the integration of the course.

#### STUDENT EVALUATION

A survey of student reaction to the course was conducted in June 1946. Mimeographed questionnaires were distributed to the members of the first two B.A. classes. They were requested to supply answers and return the unsigned sheets. The majority of each class responded to this request.

The following questions were asked of the freshman group, just finishing the Introduction to Science course. The form sheet provided space for answers.

The staff of the Introduction to Science Course would like to have your answers to the following questions as a help toward improving this course for next year's students. Please answer as many as possible and return to your instructor. You need not sign your name.

1. Which sciences did you study in high school?
2. Which science do you plan to study next year?
3. Why did you select the science chosen in (2)?
4. Would the present Introduction to Science course be more effective if the same time and material were distributed over three quarters?
5. Do you believe the Introduction to Science course is sufficiently worthwhile to add material and extend it to a regular three-quarter course?
6. What features of the Introduction to Science course do you think are (a) good? (b) poor?
7. Should a carefully correlated set of laboratory experiments be made a part of the Introduction to Science course?
8. What changes would you suggest to improve the Introduction to Science course?

The replies are as follows:

*Question No. 1 (Which sciences did you study in high school?)*

	Percentage of class
Biology	70
Chemistry	57
Physics	39
General Science	35
Zoology	2.5
Botany	1.2
Physiology	1.2

*Question No. 2 (Which science do you plan to study next year?)*

A check of the records of the first three B.A. classes show the following registration in a selected science for the sophomore year.

	Percentage of:			
	first class, second class, third class,	1945-46	1946-47	1947-48
Astronomy		11.8+	5.0	2.7+
Botany		1.7	10.0	13.7
Chemistry		11.8+	13.3+	8.2+
Geography		37.2	18.3	20.3-
Geology		6.8	0	16.4+
Mathematics		1.7	11.7	8.2
Physics		5.1	1.7-	9.6
Zoology		23.8	40	20.3-

*Question No. 3 (Why did you select the science chosen in (2)?)*

The two answers repeatedly given were either that the selected science was found to be the most interesting one of the series or that the selection was made because this science was required or needed for the student's "field of special interest."

The "field of special interest" selected by the first and second classes is as follows:

	Percentage of first class	Percentage of second class
Division I		
Science	2.9	9.1
Division II		
Social Science	61.8	52.3
Division III		
English, Art, Languages	35.3	38.6

*Question No. 4 (Would the present Introduction to Science*

course be more effective if the same time and material were distributed over three quarters?)

There was an almost equal division of yes and no answers to this question.

*Question No. 5* (Do you believe the Introduction to Science course is sufficiently worthwhile to add material and extend it to a regular three-quarter course?)

The answers were as follows:

Yes	77 percent
Yes, if mathematics is not omitted	18 percent
No .....	5 percent

*Question No. 6* (What features of the Introduction to Science course do you think are (a) good? (b) poor?)

(a) *Good.* A considerable number of replies stressed each of the following points: General organization of course, including plan of weekly quizzes; selection and correlation of subject material; small, stimulating discussion sessions and thought-provoking discussion questions; excellent demonstrations.

A few selected comments are of interest:

"The idea of touching on many sciences before you choose your field of study."

"I think weekly quizzes are wonderful. That way we are always kept on our toes and aren't so uncertain around exam time as to what we have to study."

"The weekly quiz is an excellent idea and, although the exams are probably the toughest we have, I think that so far they have also been the least ambiguous, the most fair."

"It is about time that those of us who do not wish to specialize in any one science can get a course which gives us a general knowledge. It is essential for a person who wishes to be considered educated."

'The scientists' attitude toward authority.'

"Stimulates you to think and want to read further in those fields."

(b) *Poor.* The most usual reactions are a comment that too much material was covered in too little time, or a suggestion that time should be taken from one (named) science and given to another. The other comments were quite scattered. Typical ones are:

"The quiz instructors did not always know all the material."

"I disapprove of Saturday labs."

"It shouldn't be necessary to take attendance at every lecture—it seems to me that the subject matter is interesting enough to attract all the students—makes us feel like grammar school children—who knows but we may all develop persecution complexes!"

*Question No. 7 (Should a carefully correlated set of laboratory experiments be made a part of the Introduction to Science course?)*

The answers were as follows:

Yes (many qualified no Saturday lab) .....	74 percent
Continue present plan (a single representative laboratory session sponsored by each science department) .....	10 percent
No laboratory work .....	16 percent

*Question No. 8 (What changes would you suggest to improve the Introduction to Science course?)*

In most cases the students extended the remarks made under Questions 6 and 7. The following are other typical comments:

"Distribute a bibliography of books to be read at the student's leisure during the summer or during the school year."

"I believe more field trips should be offered, not required, to places like the sand dunes or the Museum of Science and Industry."

"If less material were presented—just that which is relevant to the aim of the course—the student would have more interest and understanding."

"I would like to see the course expanded and adapted to cover two years work."

"Arrange the discussion groups according to the background of science the students have."

A longer questionnaire was given to the sophomore group. The following questions and replies are pertinent to this study.

*Question No. 3 (If you could rechoose your sophomore college science, would it be the same one?)*

Of the replies 75 percent were "yes," some of them quite emphatic. Several of the "no" answers expressed a keen disappointment in the selected sophomore science.

*Question No. 4 (Do you believe that your sophomore college science (a) has built adequately upon the background you received in the Introduction to Science course, or (b) is the current science presented in too elementary a manner?)*

There was general agreement that the present college science courses represented a satisfactory next course for these students. A few reported repetition of material.

*Question No. 6* (Do you believe the Introduction to Science course is sufficiently worthwhile to add material and extend it to a regular three-quarter course?)

There was a unanimous vote of "yes" to this question on the returned questionnaires. (It should be remembered that the majority but not the entire class returned the questionnaire.)

*Question No. 7* (In view of your sophomore experience, what features of the Introduction to Science course do you think are (a) good (b) poor?)

The replies were very similar to those already reported for the freshman class. The sophomore group stressed to a greater degree the point that the discussion leaders were not always sufficiently versed in the subject matter outside their own field. The reader is reminded that several of the instructors were teaching science outside their departmental field for the first time. The point made emphasizes also the fact that one of the problems involved in an interdepartmental course is finding a staff with the required broad training.

*Question No. 8* (Should correlated laboratory experience be associated with the Introduction to Science course?)

It is interesting to note that 64 percent of the sophomore class, just finishing their year of a laboratory science, replied "yes" to this question.

*Question No. 9* (Would you advise a new student to take (a) one year of each of two regular sciences or (b) the Introduction to Science course and one year of a regular science?)

The replies were: (a), 4 percent; (b), 92 percent; qualified, 4 percent.

*Question No. 10* (in which ways do you believe you (a) have an advantage (b) are at a disadvantage to the non-B.A. program students in your science class?)

A few selected replies point up these answers:

"I have an advantage in that when studying the science I can integrate points with the other sciences which I have studied."

"Since I am majoring in (science) and have definitely required (science) sequences to take, I am behind and therefore will have to double up in my junior and senior years."

"I believe I was at an advantage because I had a good foundation in my science. Besides, I know the principles of not only the one science I am taking now, but of other sciences."

"We are more apt to understand references to other sciences and also the scientific way of thinking and experimenting."

**Question No. 11 (What changes would you suggest to improve the Introduction to Science course?)**

The answers were quite similar to those made by the freshman group to this question. We may add these individual selections:

"More emphasis on broad theory and less on details."

"More quiz section instructors like \_\_\_\_\_ with his broad outlook and interest in fields other than his own."

"I think it would be an excellent idea to have—somewhere in the junior or senior years—a brief refresher course of the same type."

#### PLANNED REVISION

Recent faculty action has made the Introduction to Science an elective for all liberal arts freshmen and sophomores. Some students will be entering the course who already have had a year in one of the other sciences. In order to prevent significant duplication of material for these students, it then will be necessary to make at least some changes in the course.

However, this action took place at a time when a number of other factors also were exerting pressure on the course, and it was decided instead to make a drastic revision. First, the participation by a member from each department, who sat through all the lectures, makes the course expensive relative to other college courses. Although this arrangement is excellent as an ideal, there is a general feeling among the participants that the course eventually must compete with other courses on a more even basis. Second, there has been considerable criticism from other members of the science faculty, chiefly on the grounds that the course is a kind of glorified general science; that it lacks depth. In defense of this criticism, it must be said that the opinion generally is held with a strength in inverse ratio to the information the critic possesses as to what actually is taught. Third, although there has been a continuous tendency toward reduction of the number of concepts treated, there is strong feeling in the group that this number should be drastically reduced. We feel that the course is successful in its present objectives in terms of showing the underlying unity of the sciences, in presenting understandably and thoroughly many major concepts, and in provid-

ing a basis for the selection of a second science. In the revision, understanding of science by detailed presentation of the development of few major concepts and their application in many fields will be stressed.

In the revised course it is hoped that one of the features characteristic of much science teaching will be avoided—the presentation to the students of the finished products of science; the synthesis of the present state of progress, carefully boiled down to provide the greatest possible economy in getting information to the student. Laws and theories are presented, then applied.

The experimentation, the train of thought, the incredible labor which went into the accomplishments of science are to a large extent avoided. As a result the student fails to see science in action, and has little insight into the nature of the growth and change of scientific knowledge. His experience in learning is in essence the reverse of the experience of those who gathered the knowledge. Consequently he comes out of his science course to a large extent untrained in problems of integration of raw data, but with a vast knowledge of how to apply formulas.

As it is now planned, the revised course will avoid this unbalance by a careful tracing of the development of relatively few major concepts. Then, after the blind alleys have been explored, and the experiments which did not work are analyzed, and the accepted concept is examined, the concept will be applied in a series of problems which will be spread over the various fields of science. In this way actual quantitative application can be made, and the development, because of the restricted amount of material which must be presented, carried to a high level. In terms of a specific example, although not necessarily one which will be used, the concept of energy might be investigated and its development traced to the elucidation of the law of conservation of energy. Then carefully chosen problems could be given to illustrate the application of the law, and the student would gain a real insight into the difficulties of applying such fundamental relationships in the earth sciences and in biological science.

Each development might well last five or six weeks. It is our hope that the mathematics now given in a separate

quarter at the beginning of the year can be worked into this material in its appropriate places.

If the present plans materialize, this revision will be done within the next year. This treatment means a radical change in the staffing of the course. Instead of a contributor from each science, we foresee that the course (ideally) will be handled by four people—a representative from each of mathematics, physical science, earth science, and biological science. Each of these instructors will participate throughout the entire year, and there will be no marked break, as at present, between mathematics, physical science, and biological science. It is necessary, we feel, that these instructors remain in their separate departments, and substitute this course only for their beginning level teaching in their department.

The work done by the instructors in all special units of this program is evaluated and recommendations are made to the dean relative to their advancement. It is important that good work in these units receive the same recognition as given for the balance of the college work.

# The Foundations Course in the Physical Sciences at the University of Kansas City

THE PHYSICAL science course at the University of Kansas City is a part of the core curriculum in general education which is prescribed for all students in the Liberal Arts College. In its philosophy of education the university takes the position that every person properly educated for occupational success, for useful citizenship, and for a personally satisfying life should be well grounded in the basic disciplines of our cultural heritage. To implement this philosophy the core curriculum consists of a group of courses known as "Foundations" courses, which include the following:

English Composition and World Literature	Six semester hours
Foundations of the Fine Arts	Six semester hours
Foundations of Philosophy	Three semester hours
Foreign Language	Ten semester hours
Foundations of the Physical Sciences	Ten semester hours
Foundations of the Biological Sciences	Five semester hours
Foundations of World History and Government	Six semester hours
Foundations of American History and Gov't	Six semester hours

An adjustment of the foreign language requirement may be made in terms of the foreign language which the student had in high school, and substitutions may be made for the physical science course in case the student majors in one of the physical sciences. In the latter case, however, the student is required to take courses in at least two different physical sciences. It should be added that the faculty recognizes the dynamic nature of this program; undoubtedly certain changes will occur as time passes, particularly with respect to deficiencies already discernible.

By Robert Ray Haun, professor of physics, University of Kansas City.

Of these general courses physical sciences are in some ways the easiest and in some ways the most difficult to develop. No realm of knowledge has become so divided and compartmentalized in our educational system as have the physical sciences. Departments of astronomy, physics, chemistry, geology, and geography, and sometimes others, have developed with a complete independence, which has been valuable for specialization and research purposes but which has led to a separation inconsistent with the facts of the natural world. It is more logical and reasonable to present the major concepts about the physical world in one course, cutting across departmental lines where necessary; and this fact, along with the great wealth of material from which one may draw, makes the course easy to introduce. On the other hand, because of the great wealth of material, it is difficult to determine what shall be omitted; and there is always the question as to whether the things omitted may be more important than those selected for presentation. However, it should be pointed out that in every course, even those long established, some material is selected and some rejected that might have been presented just as easily. The guiding principle should be that the selection of the material as well as the method of presentation must be determined by the objectives of the course.

#### FOUNDATIONS OF THE PHYSICAL SCIENCES

The objectives of the physical science course include all three of those commonly emphasized for such courses: a comprehension of the major principles and laws which have been discovered about the physical world; an understanding of the scientific method as it has been applied in discovering these principles; and an explanation of many everyday phenomena in terms of the basic principles and laws. These objectives are emphasized in the order named, although it is recognized that other institutions reverse the order of importance, placing either the explanation of everyday phenomena or an understanding of the scientific method first. Primary emphasis is placed upon a comprehension of the fundamental and basic principles and facts about the physical universe because these are essential to a general and cultural education. Moreover, the facts and data thus presented must be available before one can present clearly the logic involved in the scientific method. Applications to the everyday phenomena are frequently made

to illustrate the fundamental principles, but no attempt is made to cover comprehensively all the applications of the principles selected for presentation.

Since the emphasis is on fundamental principles, the material is selected to cover many fundamental principles and fewer applications, with the hope that the individual will make further application at the proper time and place. (The word "hope" is used in recognition of the failings of the human mind.) For example, Newton's universal law of gravitation is discussed as a basic principle of the universe and its application to the solar system is presented, but emphasis is not given to the calculations of the distances an object will fall or the velocities it will acquire in falling for a certain period of time, even though the latter applications might be very interesting and practical in the present age.

As now given, the physical science course always includes material from astronomy, geology, physics, and chemistry. Frequently some basic concepts in mathematics and some material from geography and meteorology are included. However, the physical science course is not an assemblage of brief and condensed treatises of these subjects as they are commonly organized. Integration of material is a basic feature and ideas are introduced from various fields as they are needed. For example, the discussion of the stars has scarcely begun before the telescope is mentioned. Since questions arise about the functioning of the telescope, it is discussed at this point instead of relegating it to its conventional place in physics. To consider the telescope means that lenses must be discussed in terms of refraction; consequently refraction is presented at this time. Likewise the basic principles of reflection are presented to explain the reflecting telescope.

It is recognized that this functional and progressive approach might be carried on indefinitely. To explain refraction completely, one should discuss light waves, wave-motion phenomena, quantum mechanics, arriving eventually at the basic concepts of matter and energy. This would be true for every topic treated, since the physical world is an integrated unit and not an assemblage of separate parts. Therefore compromise must be made if knowledge is to be organized in any systematic form for treatment and presentation.

It is very interesting to note that this integration of ma-

terial is accomplished by various instructors and in various textbooks under many different outlines and plans of organization of content. All of them seem logical as one analyzes them. That there are so many logical plans of organization well testifies to the fact that the physical universe is a unit and that one may readily study it from many points of departure. The Foundations of the Physical Sciences course at the University of Kansas City has been arranged to start with a study of the entire physical universe and then to examine more closely and more intimately smaller and smaller parts of it. Major concepts and principles are studied rather than detailed and technical applications. Topics selected are discussed as deeply and thoroughly as the ability and background of the student permit. To provide a general conception of the topics which the course contains, a brief but somewhat comprehensive outline of the course follows.

#### OUTLINE AND METHOD OF THE COURSE

It begins with a consideration of the whole material universe as it is seen in the study of the stars and stellar systems. Discussion begins with the most obvious topics of number, motions, and constellations of stars. The subject of distances to the stars raises the question of methods of measuring inaccessible distances; hence triangulation is presented in the class and in the laboratory, the student being required to verify the principles of triangulation and to determine some inaccessible distance with a simple transit. The value of the telescope in increasing one's ability to study the sky is pointed out, and, as mentioned above, refraction and reflection are presented at this time. In the laboratory the student determines the focal length of some lenses, assembles them to make a telescope, and measures the magnifying power of his lens combination. A study of the sky now magnified leads to discussion of binary, multiple and variable stars, nebulae, galaxies, comets, meteors, and meteorites. The laboratory work includes at least one evening spent with the instructor studying the sky.

For a closer look, the attention is focused upon the sun as a typical star. In this connection study of the spectroscope and types of spectra helps explain the method of determining the composition of the sun. An experiment in the laboratory permits the student to use the spectroscope in studying emission

spectra and the dark-line spectrum of the sun. The characteristic features of the planets and satellites are next discussed, and Kepler's laws of planetary motion and Newton's law of gravitation introduced.

At this point cosmologies are discussed as an example of the scientific method approach to the problem of the motions of the heavenly bodies. Following this discussion assignments are made for individual student scientific method projects, which will be explained more completely in the discussion of the laboratory work of the course.

Before focusing attention more directly upon the earth, systems of reference are briefly treated. Particular attention is given to longitude and latitude and to the production of maps. The laboratory work includes a simple Mercator projection and some rough calculations of the errors in the use of such a map. The location of a point in time is also treated, with applications to various kinds of time and problems of the calendar.

Approaching the earth from the outside the class first studies atmosphere, with attention to its physical composition, its chemical composition, and the factors which change it. The laboratory work includes experiments dealing with density of air, atmospheric pressure, dew point, and relative humidity, as well as study of the weather map. Gradation, vulcanism, and diastrophism are discussed in some detail and the consequent types of rocks are considered and examined in the laboratory. At least one field trip is included. The geological time scale is presented in sufficient detail to acquaint the student with the general method and the fundamental conclusion of the historical geologist.

The next topic is concerned with the basic principles of the number system including scientific notation of numbers and a brief treatment of logarithms and the slide rule. It is recognized that this logically appears to belong at the opening of the course, but experience has shown that when presented at that time it has an undesirable psychological effect by giving an unfavorable impression of the purpose and spirit of the course. The subject is rationalized at this time by pointing out the need for the scientific notation to be used in handling the large and small numbers in the next part of the course, which deals with atoms and molecules.

Again the scientific method is used on a major problem in science, the study of the nature of electricity, the periodic classification of the elements, and the early study of radioactivity, in order to arrive at our modern concepts of the atom. Brief discussion of the nucleus and atomic energy then ensues, and attention is turned to the electrons outside the nucleus as possible explanations for polar and covalent compounds. The properties of molecules are also considered.

As the course concentrates more definitely on varieties of matter, the students first learn methods of identifying substances by their physical and chemical properties, and then, symbols and formulas, including the procedures for determining formulas from molecular weights and percentage compositions. The methods of producing compounds by direct combination, by displacement, by simple decomposition, and by double decomposition are then treated both in the classroom and the laboratory. The student is taught to write the chemical equations and to make simple calculations for the examples used. In connection with direct combination and displacement reactions, oxidation and reduction are discussed and with the double decomposition reactions, ionization presented. The treatment of ionization includes conductances of solutions, ion migration, Faraday's laws, abnormalities of solution boiling points and freezing points, and application of ionization is then made to the completion of reversible reactions by the formation of an insoluble gas, an insoluble solid, a nonionizing molecule, and a complex ion. In this connection too, the characteristic properties of acids, bases, and salts are studied. To give the student a slight acquaintance with analytical chemistry, Group I in the qualitative scheme for metal identification and the determination of the acidity of vinegar by titration are presented in the lecture and in the laboratory work. The class considers organic compounds in terms of their structural formulas, the essential groups for the more common classes of compounds being presented in the class work and modeled by the students in the laboratory period.

The course now turns to consideration of the invisible energy which produces the changes taking place in matter with an enunciation of the laws of thermodynamics and a discussion of the energy associated with the molecules previously

discussed. Temperature and the measurement of heat are followed by the effects of heat energy in producing expansion, change in temperature and change in state, and then by the methods of transfer of heat energy. Sound energy follows as a second form of energy associated with molecules and this leads to the characteristics of wave motion and applications to sound phenomena.

The treatment of mechanical energy is quite conventional except that little attention is given to anything but linear motion. Electrical energy is presented in terms of its sources, its measurement, the general principles in the electric circuit, and the effects of an electric current. The advantages and disadvantages of alternating current are briefly discussed. While some topics in light have been previously discussed in the course, it is now presented as the final form of energy, summarizing previous discussions, and in particular adding further considerations of intensity and illumination, color phenomena, and its extension to other types of radiation.

#### LABORATORY

As has been implied throughout the previous discussion, laboratory work constitutes an essential part of the course, although, according to a recent study, this is true in only about 20 percent of the institutions offering a physical science course. Undoubtedly staff and equipment constitute major problems in this connection, but the equipment is not nearly so serious a problem as might at first be expected. With very few exceptions the equipment specified in the laboratory manual for the Foundations of the Physical Sciences course is readily obtainable from the usual laboratory supply houses. The chemical experiments present the most serious problem, if they are not performed in the chemical laboratory where running water and gas are available. Even these, however, are for the most part test-tube experiments, or they involve very little apparatus, and hence with a little thoughtful adaptation can be handled in any laboratory.

Though some new experiments have been especially devised for this course, for the most part they are adaptations of regular experiments in the various physical sciences. Scientific method experiments, to be discussed presently are an important feature of the course. The regular experiments are per-

formed in two-hour periods. At the end of the period students turn in copies of the data taken and make complete reports the following week. The reports are considered an essential part of the course, since it is the only opportunity that most students will have to learn how to write a scientific report.

Since the scientific method experiments are an innovation they should be explained in more detail. The opening paragraph in the section of the laboratory manual reads as follows:

"In the previous experiments of this manual the conclusions to be obtained from the experiment have been known in advance of its performance even by the student himself as well as the instructor. The experiments have not been of a research nature in the sense that the experimenter investigates new and unsolved problems. Rather the major outcomes of the experiments have been to demonstrate and illustrate some scientific principle discussed in the lecture work of the course, to teach some fundamental procedures of measurement, to teach other laboratory techniques, and to acquaint the student with methods of interpreting data and making reports. While all of these things are essential features in the scientific method of investigation, the experiments as a whole do not illustrate the scientific procedure in solving a problem. In original scientific research the answers are not known and the conclusions to be obtained cannot be stated in advance. One makes hypotheses and sets up theories about probable answers and conclusions, but only correct interpretation of the experimental evidence enables one to arrive at the facts. The scientific or logical methods of solving a problem may be outlined as involving the following steps."

The conventional steps are then listed and a hypothetical application to an everyday problem in the buying of a fountain pen is given by way of illustration. A further illustration is given in a condensation of a student report of his investigation concerning a certain set of laboratory blocks which had presented a problem to a former class. The student is then told that he is to select a project which he will investigate of his own accord and without assistance from others. Suggestions are given about how to select the project and a list of suggestive projects performed by other students is included. The student submits a statement of his problem to the instructor who checks it for clarity of statement, prob-

able availability of data, and a general check to see that the problem is sufficiently limited in scope to enable the student to complete it within reasonable time. From this point the student proceeds on his own initiative and submits his report when his project is completed. The results obtained to date would probably justify the listing of many of these student projects and a discussion of some of the results, but that will not be done here. Several rather subjective conclusions might be noted. The number of reports obtained now approaches a thousand. About 25 percent of them are excellent and would be a credit to many graduate students. Only about 10 percent completely miss the real point of the project. Although subjects are frequently repeated, originality is common, and there is very little evidence that projects are handed down from one student to another. They seem to delight in the challenge that they are to do something original themselves. It should be added that they have been told that they will be graded not upon the correctness of their report but upon their method and procedure.

#### EVALUATION

This physical science course has been evaluated in a number of ways, some of which will be briefly discussed. Included in

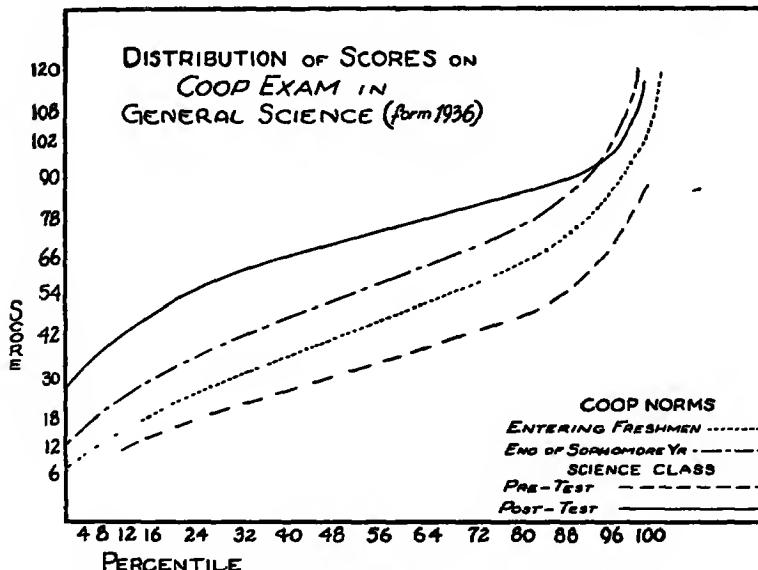


Figure 1

these will be certain studies made by the writer at the University of Minnesota while teaching and evaluating a similar course in the sciences given there.

The opinions of the course expressed by students while in college and when they return later are generally excellent. In two questionnaire studies at the University of Minnesota Liberal Arts College, 93 to 94 percent said that they would recommend a similar course to a brother or sister coming to the university. They also testified that the course compared very favorably with their other courses in interest, in cultural and practical value, in the amount of work it required of them, and in both ease and difficulty of learning.

Standardized tests have been used to show what progress is made by the group. At the University of Minnesota, the Co-operative Test Service test in general science was given to the class at the beginning and again at the end of the course. When used as a pretest, the class was found to be appreciably below the entering freshman norms furnished by the Cooperative Test Service. (See Figure 1.) This was to be expected in view of the fact that the norms were established on all types of entering students, which would include the students who are interested in and majoring in the sciences. On the other hand, the natural science class was composed of students who were not interested in the sciences and generally did not take much more than the required science course in high school. The median of the natural science class on the pretest was at the 33rd percentile of entering freshmen on the college norms. The median of the class on the posttest was at the 95th percentile of the group on the pretest. More than that, at the end of the course, the class as a whole was far above the norms furnished by the Cooperative Test Service for the end-of-the-year sophomores. The median of the class was at about the 75th percentile of sophomores as given by the national norms.

On a test to measure ability to interpret reading materials in the natural sciences, such as that used in the General Educational Development Tests, consistent gains were made by the natural science class. No national norms were available for the form of the test used, but the data available showed the class to be below the all-university norms at the begin-

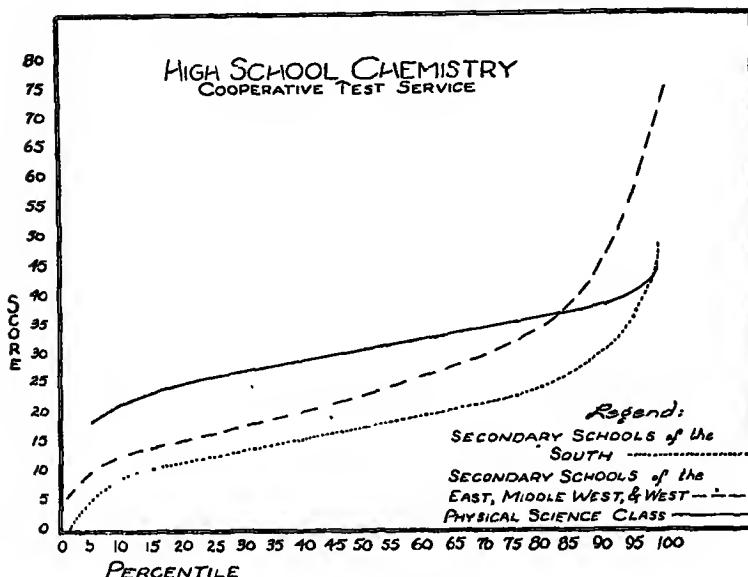


Figure 2

ning of the course and to be equivalent to or above the all-university group at the end of the course.

A similar type of study is being made at the University of Kansas City, with the physical science test being used by the University of Chicago and a number of cooperating institutions in their Evaluation of Educational Progress. The study is not complete, but the first estimates indicate results similar to those obtained in the Minnesota study.

Two specific standardized tests in chemistry have been given to the students in the Foundations of the Physical Sciences course at the University of Kansas City. On the CTS test for high school chemistry students, the physical science students ranked very high. The median of the physical science group was at the 73rd percentile for students who had had one year of high school chemistry, according to the norms furnished by the CTS for secondary schools in the East, Middle West, and West and at the 92nd percentile for the secondary schools of the South. (See Figure 2.)

The students in the Foundations of the Physical Sciences course for two years were given the CTS chemistry test for college students. Not too much was expected, since this test

is generally considered rather difficult for students who have had a full year of college chemistry, and the physical science class spent only about six weeks in specific chemistry material. Slightly better results were obtained for the smaller group the first year, but even for the second group of two hundred, the results were surprisingly good. Over half of the physical science class were above the 7th percentile, which on usual distribution curves, might easily be considered passing. (See Figure 3.) Top score made by a student who had had no other chemistry was at the 72nd percentile of students who had had a year of college chemistry, and 5 percent of the

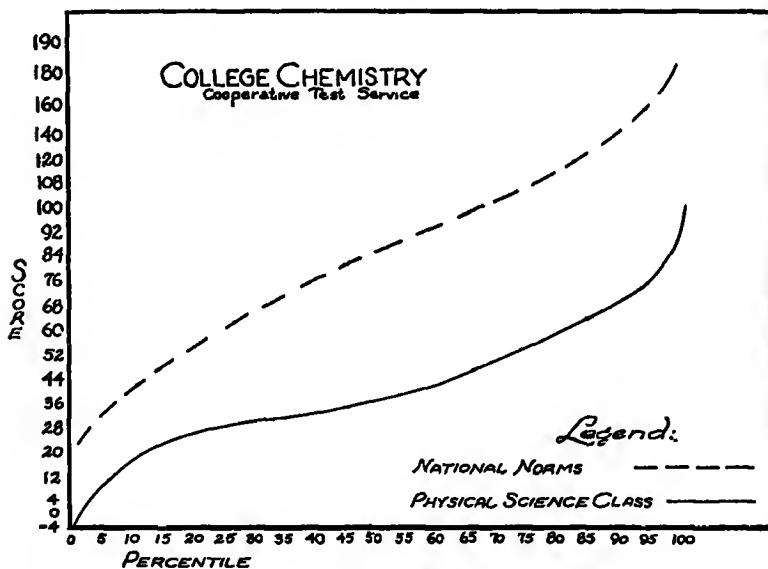


Figure 3

physical science students were above the median for the national norms. It is to be added that other studies of this group showed that, while the physical science class was below the local university norms, it was just exactly at the national norms in scholastic ability and in general achievement tests, and below the norms in science interest, so that no credit can be assigned to special ability or previous background.

#### APPRAISAL

While the administrative officers have been pleased with the course, the best appraisal probably comes from the instruc-

tors. Instructors frequently agree to teach this course with some reluctance because they feel inadequate in one or more of the areas which it covers. Almost all of them become enthusiastic over the course and develop the conviction that it is very desirable for the nonscience major.

It should be pointed out that one of the values of introducing such a course is that it removes from the regular science courses students who would take a course just to satisfy the science requirement. With only those students in general chemistry who really want to take it or who take it for professional reasons, a better course can be given and more effective teaching can be done.

It is to be added that some students who take the physical science course find an interest in one of the physical sciences that they had never previously discovered and eventually major in it. Also, the course has been effectively used as a prerequisite by students who normally would need but have not had a course in high school chemistry. Students who have completed the physical science course can successfully take the chemistry course designed for students who have had one year in high school chemistry. The course thus makes a real contribution to the chemistry and other science departments as well as to the general education program of the university.

## The Wesleyan Course In Physical Science

WESLEYAN UNIVERSITY offers two science courses specifically for nonscience majors, Evolution 1-2 and Physical Science 1-2. Evolution 1-2 takes as its central theme the evolution and development of life, and draws its material principally from biology, paleontology, and anthropology. Physical Science 1-2 treats subjects chosen from astronomy, chemistry, geology, mathematics, and physics as well as the history and philosophy of science.

The courses are designed especially for the Wesleyan student body, and adapted to the Wesleyan curriculum. Hence it is of value to describe briefly the academic climate in which they are given. Wesleyan is a small, liberal arts college with 914 undergraduates, 57 graduate students, and 108 faculty members not counting graduate assistants. Classes are comparatively small, and sections are held to 15 to 20 students. All students are required to take two one-year courses in science, one of which must be a laboratory course, and one of which must be completed before the junior year. The general science courses do not satisfy the laboratory requirement. Science majors, who comprise approximately one-third of the student body, may elect the general science courses, but have not been encouraged to do so.

The student body is selected from a very much larger number of applicants. As stated in the Wesleyan catalogue for 1947-48. "Candidates for admission normally are required to complete with certifying grades the usual college preparatory course. This must include four years of English, at least a year and a half of algebra and one year of geometry, and three years of one foreign language or two years each of two. The remaining

By John W. Abrams, chairman of Physical Science 1-2, Wesleyan University.

subjects should be primarily in laboratory science, additional mathematics, and language . . . . Having fulfilled these requirements, candidates are selected on the basis of their class standing and their record in the Scholastic Aptitude Test and three Achievement Tests of the College Entrance Examination Board." Virtually all entrants have graduated from the secondary school in the top half of their class, and 60 percent have come from the top quarter. The average College Board Scholastic Aptitude Test score for the 1947-48 freshman class was in the 62nd percentile, verbal, and 69th percentile, mathematical. Sixty-eight percent of the class presented four years of mathematics for entrance. The average I. Q. of the class was 121 (Otis).

*The courses in general science are open only to junior and senior students.* One college science course, normally a laboratory course, must have been completed previously. In addition to entrance mathematics, Physical Science 1-2 presupposes an acquaintance with the philosophical systems of Plato, Aristotle, and Descartes gained through a required freshman course in the humanities. The course extends over two semesters, and meets three times a week. There are 89 class meetings, including four one-hour midsemester examinations. Three-hour finals are given at the end of each semester.

#### PRESENTATION OF THE COURSE

Three methods of presentation are employed in Physical Science: (1) formal lectures, about half of which are given by visiting lecturers, (2) informal lecture and demonstration sessions, and (3) section round-table discussion groups. Other faculty members besides the section leader are frequently invited to join in the discussions.

There is no definite text for the course, although extensive assignments are made in Dampier's *History of Science*. Other assignments are of the following types:

1. Original sources—for example, Galileo's *Two New Sciences*.
2. Secondary sources—for example, Mach's *The Science of Mechanics* for a discussion of Simon Stevin and the inclined plane.
3. Mimeographed commentaries and explanations written by the chairman on certain original papers considered too diffi-

cult for the student to read without some guidance—for example, on Newton's *Principia*.

4. Mimeographed sheets containing the basic principles of a particular field or topic in highly condensed form—for example on non-Euclidean geometry.

5. Mimeographed translations of material otherwise inaccessible—for example, Copernicus' *De Revolutionibus*. Some 400 pages of mimeographed material are distributed during the year. The preparation of much of this material in more permanent form is in progress.

The course attempts to provide the nonscience student with an appreciative understanding of the nature of science—its aims, its methods, and its philosophical bases. No attempt is made to survey extensively the various fields of physical science although material is drawn from all fields. The connecting thread for the material is historical and methodological. However, the connecting thread must and does connect large blocks of factual material. This material is chosen with regard both to its intrinsic importance, and its suitability as a methodological illustration. Consequently, no one field of science is covered sufficiently well so that the course may serve as prerequisite for a traditional advanced course in that field. This should not be interpreted to mean that subjects are presented in a superficial manner. They are presented as rigorously, if not as exhaustively, as they would be in a traditional course, and in a far more critical light. Certain topics are presented which are rarely encountered outside of graduate physics or mathematics courses, because it is felt that their importance justifies inclusion at least in their simplest aspects. Non-Euclidean geometry, relativity, and quantum mechanics are examples.

The historical method has been chosen for several reasons. First, science is more readily shown to be a developing and growing process rather than a mass of uninterpreted factual material and unconnected methods. Second, the interrelationships of science with other fields of knowledge are easily illustrated when one considers the origin of scientific concepts. Third, new concepts in science can be more readily assimilated when they are viewed alongside the particular problem responsible for their postulation or development. Fourth, simpler and more concrete ideas can be used to lead up to the modern complex and more abstract ones. Finally, the history of science

is considered to have considerable intrinsic value in its own right as another aspect of the history of civilization.

Similarly the philosophical bases of various scientific concepts are emphasized in their historical context. This is done primarily to illustrate the essential value of the philosophical connections of science to its development. Consequently, relationships between science and other disciplines are emphasized. A conscious effort is maintained to integrate the philosophical relationships between natural science, social science, and religion throughout the course. Those divisions of the philosophy of science dealing with fundamental concepts and with logic and methodology are treated. By use of various incidents in the history of science, it is shown how interpretation of factual data may differ, depending on whether they are considered in the light of a philosophy which places its concept of reality in matter, mathematics, or function and organization. Hence the pre-Socratics, the Pythagoreans and Plato, Aristotle, Newton, Einstein, Eddington, and Whitehead are considered both as scientists and philosophers.

As this course attempts to show the close relationships of various fields of human knowledge, it is felt that any attempt to consider separately the various branches of science would be out of place. The division of science into two parts, physical and biological, is probably unfortunate but has been accepted as an alternative either to weakening the course by spreading it over too much material or expanding the course to two years. Much of the value of the course lies in its intensive nature, which should probably be maintained even at considerable cost. The offering of two separate one-year courses appears to be a satisfactory compromise, particularly as students may elect both courses.

#### SELECTION OF CONTENT

The material presented in Physical Science 1-2 is selected from all branches of physical science. The reasons for the choice of specific material are many and varied. Few topics have been chosen for one reason alone. The principal reasons are:

1. The factual material is sufficiently important either in its own right—that is, it is considered an essential prerequisite

to the formulation of an intelligent world picture—or has had a profound effect on man's thought.

2. The process is considered an excellent example of a particular type of scientific methodology. Preference is given to the inclusion of the earliest application of a method and subsequent cases are chosen to illustrate the expansion of the method and its applicability to other branches. In a few cases here we have stepped over into the biological sciences.

3. The material introduces a new concept of importance.

4. The material is required or is desirable as prerequisite to material which will be presented later in historical context.

5. The material is considered necessary to sustain the historical connecting thread.

Major branches of physical science have been represented by at least one important subject each, and minor illustrations are taken from as many varied sources as possible. However, it should be re-emphasized, no attempt is made to make the course complete. No person is more aware than the author that the present course omits or mentions only most casually many extremely important subjects in physical science. To mention a few: organic chemistry, hydro- and aerodynamics, meteorology, symbolic logic, electronics, and mineralogy are certainly neglected. They have not been overlooked. They have been left out because it was necessary to make a selection of material, so that the included subjects could be treated thoroughly. This selection, however, is by no means rigid. The course is being constantly revised according to the needs and capabilities of the students. Succeeding revisions may well reject material now included, in favor of some that is now excluded. In several cases the margin of preference for a particular topic is so slight that the choice should depend on the instructor and students in each particular case. However, care must be taken not to destroy the historical, methodological, or philosophical framework.

In order to sustain interest, facilitate thoroughness of treatment, and weld the course into a smoother whole, a few specific topics have been included to run throughout the course. These may be noticed in the detailed study below. They include: light and optics, the treatment of infinitesimals, space and geometry, mechanics, and the theories of the solar system.

They are not brought out explicitly, but have contributed much to the continuity of the course.

The preceding sections have endeavored to show the underlying philosophy of this particular course in physical science, and the environment in which it is given. What follows is an outline of the 1947-48 course, with the inclusion of some revisions to be introduced in 1948-49. As it is often quite difficult to deduce the spirit and practice of a course from an outline, however long, these introductory statements should be of value. However, a few words might be added. In each section a great number of specific topics is listed. Equal time is not devoted to each topic, but rather much the larger part of each section is devoted to one or two highly specific considerations. Many topics listed under a lecture appear only in the reading assignments, and are not mentioned in the lecture or recitation itself. They reappear, of course, in the round-table discussions normally initiated by students.

#### COURSE OUTLINE

##### *First Term*

###### BLOCK I—INTRODUCTION AND EARLIEST SCIENCE IN EGYPT AND THE NEAR EAST

###### (1-2)<sup>1</sup> Introductory lectures

The questions, "What is science?" and "Why should science be a part of one's liberal education?" are posed and tentatively explored. The following points and connections are emphasized:

1. Science as a part of man's heritage
2. Science and philosophy—Northrup's treatment in *Science and First Principles* followed in a modified manner
3. Science, technology, and social need—the idea of science as a means to control nature is discussed
4. The position of science in modern life
5. The historical approach to science
6. The goals of science
7. Bases upon which science is developed
8. The meaning of controlled experiment, observation, hypothesis and theory, and their place in the structure of science

###### (3) Discussion on the introductory lectures

###### (4) Lecture: "The Origins of Science"

An anthropological lecture following Frazer and Malinowski which treats the early connections between science, pseudoscience, magic, and religion. Ideas, which appeared in prehistory—such as number, causality, and uni-

<sup>1</sup>Numbers in parentheses refer to class meetings.

formity of nature—and were essential to the growth of science, are emphasized.

(5) Topic: Babylonian Astronomy and Astrology

The apparent motions of the heavenly bodies are described. The relations between astronomical motions, time reckoning, and calendars are shown and their obvious social implications extracted. The need for numerical systems in measurement is shown. The idea of variable velocity is introduced along with the Babylonian solution. Primitive observational instruments are demonstrated, and their utility and value considered. The nature of Babylonian science is discussed.

(6) Topic: Egyptian Science

Surveying and mensuration are discussed along with their connections to land ownership, trade, and architecture. The Egyptian number system is introduced and compared with the Babylonian. The utility of number systems in general is discussed. The two views of Peet and Chace on Egyptian science are contrasted.

(7) Discussion

Attempt is made to center this discussion on a comparison of Babylonian and Egyptian science.

## BLOCK II—EARLY GREEK SCIENCE

(8) Lecture: "Science and Greece"<sup>2</sup>

The background against which Greek science developed is described. The lecture is presented in accordance with the belief that science is not an isolated field of human endeavor and that the factors which have influenced science and scientists should be studied alongside the subject matter of science.

(9) Lecture: "The Pre-Socratics"<sup>3</sup>

The fundamental problems of natural philosophy—that is, those of matter, change, continuity, and void—are introduced in the form in which they were conceived by the various pre-Socratic schools. Parmenides and Heraclitus are contrasted, and Zeno's paradoxes discussed.

(10) Discussion

(11) Lecture: "The Pythagoreans and Plato"

The Greek conception of mathematics and mathematical proof is contrasted with earlier mathematics. The Pythagorean theorem is used to extend the concept of number to include irrationals. Number mysticism is briefly touched on. A brief review of the Platonic conception of nature and reality is given, and the effect of realism on scientific inquiry is emphasized. Synthesis and analysis are introduced as modes of mathematical reasoning.

(12) Topic: Contributions of Aristotle and His School

The valuable contributions of Aristotle to science are emphasized rather

<sup>2</sup>Given by N. O. Brown, assistant professor of classics.

<sup>3</sup>Given by J. R. Everett, assistant professor of philosophy and religion.

than the yoke cast upon science by his scholastic followers. The elements of Aristotelian logic are presented as criteria for a consistent system. The fundamental philosophical differences between Aristotle and Plato are recalled to the student and their effect on interpretation of science brought out. The classification methods developed by Aristotle and Theophrastus are treated, and the contributions of the early Aristotelians to mechanics are studied.

- (13) Discussion
- (14) Hour examination<sup>4</sup>

#### BLOCK III—HELLENISTIC AND ALEXANDRINE SCIENCE

- (15) Topic: Deductive Reasoning and Geometry

The nature, significance, and utility of axioms are treated in the manner of Aristotle. The structure of synthetic geometry and the application of deductive methods are illustrated by a careful discussion of selected theorems from Euclid. The nature of the parallel postulate is called to the student's attention. Conic sections are introduced, and defined after Apollonius and Pappus.

- (16) Topic: Applications of Geometry to Mechanics—Archimedes

The applicability of synthetic geometric methods to problems of statics is illustrated by selections from Archimedes. The laws of hydrostatics are mentioned, but emphasis is placed upon the determinations of areas of curved figures—the circle and the parabola—and the treatment of infinitesimals and infinity. Archimedes' use of experiment is brought out and selected propositions demonstrated experimentally.

- (17) Topic: Astronomy and Optics in the Alexandrine Period

The astronomical system of Aristarchus is discussed along with that of Ptolemy. The application of geometry to astronomy is introduced through the work of Eratosthenes on the size of the earth and Hipparchus on the distance of the moon. Geometric optics, which run as a secondary sequence for several lectures, are introduced through the definitions and axioms used by Euclid and Ptolemy.

- (18) Discussion

Reading assignments for this class include short readings on alchemy (mimeographed) and on Roman science.

#### BLOCK IV—MEDIEVAL SCIENCE

- (19) Lecture: "The Medieval Period"<sup>5</sup>

The bases of thought in the Western world during this period are discussed with regard to their effect on the prevailing attitude toward science. The entire lecture illustrates how profoundly both religion and philosophy have affected the development of science.

<sup>4</sup>See Appendix A.

<sup>5</sup>Given by R. Lopez, visiting associate professor of history, 1947-48.

## (20) Topic: Moslem and Hindu Science

A brief résumé is given of the development of science in the East. The experimental science of the medieval Arabs is introduced through the specific gravity measures of Al Biruni and the optics of Alhazen. Alhazen's experiments on refraction are demonstrated in class. The focusing properties of spherical mirrors and lenses and the use of paraboloidal mirrors to eliminate spherical aberration, are demonstrated.

## (21) Discussion

(22) Lecture: "Averroes, Maimonides, and Aquinas"<sup>16</sup>

The philosophical and religious syntheses of these men are discussed as to their effect on science. The nature of scholasticism is brought out.

## (23) Topic: Medieval Precursors of Modern Science

Geometric optics are continued with the work of Roger Bacon. The major emphasis is placed on the experimental method used by Roger Bacon and Cusa, and its relation to modern science. Cusa's philosophical position is considered, eventually to be reconsidered along with Dirac.

## (24) Hour examination

## (25) Lecture: "Leonardo and the Renaissance"

The spirit of the Renaissance is approached through the works of Leonardo da Vinci. Material from his notebooks is discussed and analyzed with particular weight placed on his extension of statics and virtual development of dynamics.

## (26) Topic: Statics

Static equilibrium, the inclined plane, and the triangle of forces are introduced. Simon Stevin's methods are used but with modern vector notation.

## (27) Discussion

## (28) Topic: The Solar System

The works of Copernicus, Tycho, and Kepler form the basis of discussion. Their principal astronomical discoveries are presented, and their philosophies and methodologies compared and contrasted, Tycho's instruments are considered, and the value of accurate measuring instruments to quantitative science pointed out.

## (29) Topic: The Empirical Thread in Renaissance Science

Gilbert's descriptive work on magnetism is presented. His methodology is contrasted with that of Kepler. Francis Bacon's conception of science is discussed.

## (30) Discussion

## (31-32) Topic: The Works of Galileo

The position of Galileo in the history of science is shown. Galileo's astronomical work is described, and the optics of Galilean and Keplerian telescopes given. Galileo's fundamental work on motion in setting up

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\*Given by J. R. Everett.

the basic definitions of kinematics is thoroughly treated. Equations of motion for freely falling bodies and simple trajectories are discussed.

(33) Discussion

This session is held at the Observatory in the evening so that the students have the opportunity to examine and look through telescopes.

(34) Topic: Analytic Geometry

The methods of analytic geometry are contrasted with those of synthetic geometry. The equations of the straight line, circle, and parabola are derived. Readings are given in Descartes, but modern notation is used. Problems in analytic geometry are assigned.

(35) Lecture: "The Beginnings of Modern Chemistry"<sup>7</sup>

The basic philosophical position underlying the science of chemistry is presented and contrasted with that of alchemy. Boyle's definition of element in the modern chemical sense is discussed and its relation to modern chemical ideas.

(36) Discussion

The role and significance of scientific societies (mentioned in readings) are also a subject of discussion.

### BLOCK V—NEWTON

(37) Lecture: "Sir Isaac Newton"<sup>8</sup>

An outline of Newton's life, works, philosophy, and place in the development of science.

(38) Topic: Newtonian Mechanics

The introduction, definition, axioms, and selected propositions of Book I of the *Principia* are considered.

(39) Topic: Optics

Selected topics from Newton's *Opticks* are presented, particularly the sections on refraction, dispersion, and colors. Reflecting telescopes are described. The wave (Huygens) and corpuscular (Newton) theories are touched on. Experiments given in the *Opticks* are demonstrated.

(40) Topic: Calculus

It is shown how Newton's development in mechanics called for extensions of the known mathematical methods and that the fluxional calculus resulted. The fundamental problems of the differential and integral calculus are given and related to mechanics. Modern notation is used.

(41) Topic: The Philosophical Bases of Newtonian Mechanics

Newton's definitions and *Rules for Reasoning in Philosophy* are critically examined. The Newtonian metaphysics, or lack of conscious metaphysics, are discussed.

(42) Discussion

End of first semester—three-hour examination.

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<sup>7</sup>Given by J. Gomez-Ibanez, assistant professor of chemistry.

<sup>8</sup>Given by B. C. Camp, professor of mathematics.

*Second Term***BLOCK I—EIGHTEENTH CENTURY SCIENCE**

## (1) Lecture: "The Post-Newtonian Era"

The extension of mechanical methods to other fields as a result of the success of the Newtonian synthesis is shown. Newton's influence on the Continent is traced through Voltaire to the Encyclopedists. Methods of dissemination of scientific knowledge are discussed.

## (2) Topic: Further Developments of Mechanics

The concepts of work and energy are introduced along with the ideas of minimal and conservation principles. The refinement of celestial mechanics is considered and its relationship to the rise of determinism.

## (3) Discussion

## (4) Topic: Chemistry

Selections from the work of Lavoisier, Priestly, Black, and Cavendish are presented. The problems of combustion are considered along with the rise and fall of the phlogiston theory. The importance of the balance and of quantitative measurements in chemistry are brought out.

## (5) Topic: Atomic Theory

The laws of combining weights and simple volume ratios are given along with their explanation by the atomic theory of Dalton. The system of elements and the periodic system is discussed and also used to illustrate a value of classification methods.

(6) Lecture: "Inorganic Evolution"<sup>8</sup>

Although short remarks on geology are made earlier in the course, particularly in connection with Leonardo, Stevin, and Steno, this represents the first serious treatment of geology. The uniformitarian and catastrophic theories are presented in their early forms. The philosophical significance of evolution theories is shown.

## (7) Discussion

**BLOCK II—CLASSICAL HEAT AND THERMODYNAMICS**

## (8) Topic: Heat and Energy

Quantity of heat, specific heat, and temperature are defined. The mechanical equivalent of heat and the first law of thermodynamics are introduced. The general gas law is brought in as a preliminary to the study of thermodynamic methods.

## (9) Topic: Thermodynamic Methods, Entropy

The second law of thermodynamics is given and the concept of entropy introduced. Isothermal and adiabatic changes are defined, and the Carnot cycle studied both as an ideal engine and as an example of the method of idealized experiments.

## (10) Topic: Kinetic Theory of Gases

The kinetic theory model is used to give a micromechanical picture of the phenomenon of gas pressure. The theory is elaborated and used as a link between a detailed mechanical treatment and a statistical one.

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<sup>8</sup>Given by J. W. Peoples, professor of geology.

- (11) Discussion
- (12) Hour examination

### BLOCK III—NINETEENTH CENTURY CLASSICAL SCIENCE

- (13) Topic: Electricity and Electric Current

The concept of field is introduced and elaborated upon. The method of field theory is used to explain inductance. The profound effect of inducted currents on technological advance is pointed out, and social implications discussed.

- (14) Topic: Wave Theory of Light

The wave theory of light is reintroduced and light identified as electromagnetic radiation. The works of Fresnel and Young on interference are given and demonstration experiments performed. Determinations of the velocity of light are treated, and the "experiment crucis" of the determination of the velocity of light in water considered.

- (15) Discussion

- (16) Topic: Chemical Reactions and Equilibria

Chemical valence is introduced along with ionization and electrochemistry. Sample chemical reactions are studied, and chemical equilibrium treated.

- (17) Topic: Spectroscopy

Kirchoff's laws and the methods of exciting spectra are presented. The nature of monochromatic light is reviewed, and the Doppler effect treated. Applications of spectroscopy to chemical and astrochemical analysis are shown.

- (18) Discussion

- (19) Lecture: "Non-Euclidean Geometry and the Problems of Space"

This lecture shows the more general approach to geometry of Gauss, Lobatschewski, Bolyai, and Riemann. Geodesics are considered as an extension of the idea of straight line. The philosophical implications are treated after the manner of Henri Poincaré and Whitehead.

- (20) Topic: Aether Drift and the FitzGerald Contraction

The Michelson-Morley experiment is explained in detail, and its implications elaborated upon. The FitzGerald contraction is introduced. Galilean relativity is reintroduced and thoroughly discussed.

- (21) Lecture: "Philosophy of Nineteenth Century Science"

The influence of the philosophical writings of Kant, Hume, Comte, and Hegel upon nineteenth century science are discussed. The interpretation of science by Mach, Poincaré, and K. Pearson is offered for consideration. The so-called "warfare between science and theology" is discussed.

- (22) Discussion

**BLOCK IV—BREAKDOWN OF CLASSICAL SCIENCE****(23) Lecture: "Radioactivity and the Radiation Laws"<sup>10</sup>**

These two topics are introduced as exemplifying phenomena which could not be explained by nineteenth century science. The concept of black body is introduced along with the radiation laws.

**(24) Topic: Quanta**

Quanta are introduced through Planck's law, the photoelectric effects, and Brownian motion. Analogies with material atomism are drawn.

**(25) Topic: Atomic Models**

A brief history of atomic models is given, and the Bohr theory used to exemplify a simple model. The nature of models in general is discussed and the "as if" philosophy considered. The origin of spectra is considered in its relation to atomic models.

**(26) Discussion****(27) Topic: Interactions of Light and Matter**

X-rays and crystal structure, and the Compton effect are both described. The connections between x-ray spectrum, atomic number, and atomic structure is drawn. The breakdown of the classical treatment of the Compton effect is used to show the need for relativistic treatments.

**(28) Lecture: "The Spectral Theory of Relativity"**

A general, elementary lecture introducing space-time, relativistic mass, etc. It should be noted that considerable background for this lecture has been presented earlier.

**(29) Hour examination****(30) Topic: Gravitation and the General Theory of Relativity**

A simple treatment in the manner of Einstein and Infeld is given.

**(31) Discussion, principally on the philosophical implications of relativity.****BLOCK V—THE MODERN PICTURE****(32) Lecture: "The Age and Structure of the Earth"<sup>11</sup>****(33-34) Lectures: "The Astronomical Universe" and "Astrophysics"**

Throughout this block an effort is made to present a picture of the universe in the light of the present-day science. In the first of these two lectures, the earth and, in the second, the astronomical universe are treated in an evolutionary light. Emphasis is placed on the tools and methods used. Modern cosmologies are discussed in the astrophysical lecture.

**(35) Discussion****(36) Topic: Wave Properties of Matter**

Although not presented as a formal lecture, this and the following meeting actually continue the thread started in the preceding two lectures.

<sup>10</sup>Given by V. E. Eaton, professor of physics.

<sup>11</sup>Given by J. W. Peoples.

They treat microscopic phenomena as opposed to macroscopic. The dualistic behavior of matter is compared with that of light. Heisenberg's uncertainty principle is brought in. The fundamental bases of Schrödinger's wave mechanics and Heisenberg's matrix mechanics are presented.

(37) Topic: Fundamental Particles

Evidences for the various fundamental particles are presented and their natures discussed. The meson is used to introduce cosmic rays.

(38) Lecture: "Nuclear Research and Nuclear Energy"<sup>12</sup>

This lecture continues the sequence above, and also introduces the current topics of atomic energy control, and the social implications of atomic energy in peace and war.

(39) Discussion

BLOCK VI—SUMMING UP

(40) Lecture: "The Philosophical Implications of Modern Physics"

(41) Lecture: "Reality and Modern Science"

(42) Lecture: "Science and Society"

These three lectures form a unit. Their titles are almost self-explanatory. The first shows how modern science has affected the most fundamental concepts of our existence. The second compares the views of reality of Einstein, Eddington, Whitehead, and Dirac. The third points out the place of physical science in our social structure.

(43) Discussion

End of second semester—three-hour examination.

This outline shows the material contained in the course. Ideals and objectives have already been stated, but perhaps the best clue to the intrinsic nature of the course lies in the examination questions given in Appendix A.

It should be emphasized that this course has been developed to meet the circumstances of student and curriculum found at Wesleyan. In its present form it is scarcely suitable for transplantation, but the material and structure are sufficiently viable that they should survive in another environment. Maintaining the course as one for upperclass students only has been found satisfactory to date, and is a procedure that can be recommended, as the greater maturity of the students has made possible a much more thorough and significant treatment.

The course has been proceeding quite smoothly with no major difficulties. Some difficulty has been experienced in

<sup>12</sup>Given by H. E. Duckworth, associate professor of physics.

obtaining source material, but this is being obviated. The course does, however, place a very heavy load on the instructor, but to one embued with the desire to teach it is a most rewarding and stimulating experience.

#### APPENDIX A—SAMPLE EXAMINATION QUESTIONS

1. What is the synthetic geometric type of scientific reasoning? What does it entail? Comment on its strength and weaknesses. Give a detailed, specific example of its application.
2. What are the fundamental concepts of chemistry? Why did they not develop earlier in the history of science? How did alchemy differ from chemistry in its basic concepts?
3. State the basic problems of the fluxional calculus of Newton and show how they are related to mechanics.
4. What are Kepler's laws of planetary motion? How did Kepler devise and explain them? What was he looking for? What was the current significance of a heliocentric theory? Contrast Kepler's discovery with Newton's proof.
5. What is meant in Newtonian mechanics by:  
(a) mass—comment on Newton's definition, (b) force, (c) time, (d) work, (e) energy.
6. Describe the determination of the velocity of light in water. Show in detail why this was considered an "experiment crucis" for the wave and corpuscular theories of refraction.
7. Describe the Michelson-Morley experiment and discuss the significance of its results. What is a null experiment?
8. Discuss combustion. Give a mechanical picture of what may happen when something burns. What conditions must be fulfilled?
9. Describe the Bohr model of the atom. Wherein is it contrary to classical mechanics? Relate it to the Balmer series in hydrogen. Discuss the utility of the model in the light of "as if."
10. Discuss the implications of: (a) statistical equilibria, (b) relativity, (c) the uncertainty principle on the classical concept of causality.

## APPENDIX B—READING LIST

In addition to regular assignments in Dampier, selections from the following books are required. Articles from the periodical literature, although often assigned, are not listed here.

Apollonius:	<i>Conics</i>
Archimedes:	<i>The Works of Archimedes</i> <i>The Method of Archimedes</i> (translated by Sir T. L. Heath)
Aristotle:	<i>History of Animals</i>
Arrhenius, S.:	<i>Conductivity of Electrolytes</i>
Baker, J. R.:	<i>The Scientific Life</i>
Chace, et al.:	<i>The Rhind Mathematical Papyrus</i>
Conant, J. B.:	<i>On Understanding Science</i>
Copernicus, N.:	<i>Commentariolus</i>
Dalton, J.:	<i>New Systems of Chemical Philosophy</i>
Descartes, R.:	<i>Geometry</i>
Eddington, Sir A. S.:	<i>The Philosophy of Physical Science</i>
Einstein, A. and Infeld, L.:	<i>Evolution of Physics</i>
Euclid:	<i>The Elements</i>
Farrington, B.:	<i>Greek Science</i>
Frank, P.:	<i>Between Physics and Philosophy</i>
Galilei, Galileo:	<i>Sidereal Messenger</i>
Gamow, G.:	<i>Two New Sciences</i> <i>Mr. Tompkins in Wonderland</i> <i>Mr. Tompkins Discovers the Atom</i> <i>Birth and Death of the Sun</i>
Gilbert, Sir W.:	<i>On the Lodestone</i>
Jeans, Sir J. H.:	<i>Physics and Philosophy</i>
Laplace, Marquis S.:	<i>System of the World</i>
Leonardo da Vinci:	<i>Notebooks</i>
Mach, Ernest:	<i>The Science of Mechanics</i>
Newton, Sir I.:	<i>Principia</i> <i>Opticks</i>
Pearson, K.:	<i>The Grammar of Science</i>
Plato:	<i>The Republic</i>
Poincaré, H.:	<i>Foundations of Science</i>
Ptolemy:	<i>Almagest</i>
Sarton, G.:	<i>The Faith of a Humanist</i> <i>Essays on Science and Philosophy</i>
Whitehead, A.:	<i>Science and the Modern World</i> "Scientific Method" ( <i>Encyclopædia Britannica</i> , 14th ed.)
Wolf, A.:	<i>History of Science, Technology, and Philosophy in the 18th Century</i>

## Natural Science at Pennsylvania College for Women

**N**O PROGRAM of general education in natural science can be fairly evaluated except in terms of the total curricular framework in which it is placed. This framework, if it is to be more than a reiteration of broad and obvious generalizations, must be built on certain convictions concerning the nature of the educational process. When the faculty of Pennsylvania College for Women seriously began to restudy its program, it realized that no piecemeal reorganization was adequate; that a clear statement of an educational philosophy for a liberal arts college must be developed before any new curricular patterns could be considered. It was further recognized that no program would be effective which was imposed either by the administration or by a strongly vocal minority of the faculty. A committee of nine, broadly representative of the major areas of study and of various faculty ranks, was, therefore, elected by the faculty to carry on this study.

Liberal education was conceived as the development of those qualities of mind and emotion necessary for the successful performance of the major functions of life. These seem to fall into three categories — professional competence, social responsibility, and resourceful personal living — all interdependent and interrelated. Liberal education in this sense is general education, for it strives for comprehensive understanding of human life in terms of the social environment and in terms of the laws of the natural world. It attempts to inspire in the student a range of interest, a depth of appreciation, and the agility of thought and action needed for living effectively in a democratic society.

By Earl K. Wallace, professor of chemistry, Pennsylvania College for Women.

### EDUCATIONAL GOALS

The faculty accepted the thesis that, although the process of education must be individualized, the goals of education are the same for all and hence much of the content of every student's course should be identical.<sup>9</sup> Content, however, was thought to be discussed most profitably within the framework of those abilities, attitudes, and beliefs which make for wisdom, a deep understanding of life, and an effective means of adjustment to it.

Eleven abilities felt to be essential are:

1. To express oneself clearly in speech and writing
2. To employ critical and emotional insight and imagination
3. To seek out sources of information adequate to the task involved
4. To remember selectively and precisely
5. To observe with care and discrimination
6. To concentrate on a given problem until an adequate conclusion is reached
7. To make unbiased, objective judgments, based upon knowledge
8. To synthesize and correlate
9. To express oneself creatively
10. To apportion one's time wisely and to use it productively
11. To live and to cooperate with others.

Socially constructive attitudes which the faculty believed the student should express in living are:

1. Perseverance in the pursuit of knowledge and understanding
2. Integrity in thought and action
3. Courage to take the initiative
4. Critical appraisal of one's abilities and achievements
5. Understanding and appreciation of other races and cultures
6. Eagerness to develop spiritual insight.

Beliefs fundamental to democratic society which the student should learn to recognize and act upon are:

1. That the individual is an object of dignity, deserving understanding and sympathetic consideration
2. That men are social beings whose interests are vitally interdependent

3. That human institutions and laws are a product of common agreement, and every individual has a responsibility for their support and constant improvement
4. That all significant human endeavor issues from a concern for the truth.

It is not presumed that all of these abilities, attitudes, and beliefs can be taught directly, but since they are thought to be the marks of the truly cultured person, they serve as criteria in the reconsideration of the curricular and extracurricular programs of a college, and methods should be adopted and emphases made with these desiderata in mind.

#### A NEW CURRICULUM

In the course of thought and discussion, it became increasingly clear that the conventional pattern of curricular requirements (if there ever was any clearly defined pattern) was inadequate for the development of the abilities, attitudes, and beliefs listed. Hence the faculty turned to a consideration of those areas of knowledge and those concepts which are basic to effective personal adjustment in the modern world. It was felt that every student should understand himself biologically and psychologically, the universe he inhabits, his social relationships, man's aesthetic achievements, and his attempts to organize his experience. From the standpoint of necessary knowledge the curriculum was thought of as being divided into these five areas, and the gathering together of the *basic* knowledge in each was attempted, this knowledge to be correlated both within itself and with material in other areas. This ambitious task led to the belief that only as requirements were developed for all students in these areas would an adequate program of general education be provided. A program of 63 semester hours in general education consequently became a requirement for graduation.

The new courses developed for this program are the following:

1. Human Development and Behavior, a six-hour course which includes physical and mental hygiene, human biology, and psychology.
2. A two-year sequence in Natural Science.
3. A series of three courses in social relationships: History of Western Civilization, an eight-hour course in our cultural

development; Modern Society, a six-hour course concerned with the institutions and problems of contemporary social life; and World Culture, a three-hour course in major existing cultures (oriental and occidental) and the problems of international relations.

4. A two-year sequence in The Arts, six hours each year, concerned with the nature of the various arts, their chief contributions and their social significance. Literature, the visual arts, drama, and music are included.

5. Philosophy of Life, a six-hour correlating course to be taken in the senior year.

In addition, every student must pass a test in computation, and must take courses in English (four hours correlated with other first-year studies) and speech (four hours correlated with Modern Society). Since achievement is considered more important than "taking" courses, students may be exempted in many fields by examination.

#### A NEW PROGRAM IN NATURAL SCIENCE

The natural science faculty, charged with the preparation of a program which would reinforce the ideas, beliefs, and attitudes which the faculty had determined to be essential to the well-educated person, was confronted at once with the problem of how natural science was to be taught to help achieve these aims. What purposes, aside from giving factual information, should be stressed which would lead the student to agree with our aims? What sciences should be included? What order and method of presentation should be used?

The natural science committee realized that its problem was to determine in what ways science could implement the aims of general education as stated by the faculty. What purposes should be uppermost in the mind of the instructor while teaching the functions of catalysts, the theory of mitosis, the laws of thermodynamics? How might the student be led, through the teaching of science, to acquire that background most necessary for the educated person?

After a good deal of heart-searching, the committee was able to list the aims of natural science teaching:

1. It should enable the student to formulate hypotheses.
2. It should teach him to check his hypotheses by experimentation.

3. It should lead him by natural steps through the history of scientific thought, from its beginnings to the present.
4. It should show how to apply scientific principles to the needs of modern life.
5. It should instill in him knowledge of the means of arriving at the truth.
6. It should give him an appreciation of the truth.
7. It should teach him how to express the truth accurately.
8. It should impart a fuller knowledge of the physical world.

The achievement of these aims, the committee felt, would be a contribution of natural science to the development of the well-educated person. It was realized that science would emphasize some of the general aims more than others; it was also apparent that some of the aims could be best attained through cooperation with other departments. The English department, for instance, was also concerned with the accurate expression of truth, and arrangements were needed to effect this cooperation.

#### *Selection of science course content*

Once the committee had decided on the aims which it felt should be stressed in the courses that science was to offer in general education, its next problem was to consider what sciences were to be included. In attempting to find a solution, it was clear that the factors of previous preparation on the part of the average student, the amount of time that the faculty was willing to allow to science, the selection of material to be used, the abandonment of traditional courses, and the order of presentation had to be balanced.

The average freshman entering college has had a year's general science, designed to give him simple explanations of the facts of nature, but in such a course only a superficial view of science can be given. The student has also usually taken a year course in biology, chemistry, or physics. A wisely planned science curriculum for the average student will not attempt to round out this spotty and limited secondary school training, but will instead assume that the student has only a vague and disconnected idea of the major areas of science. Since the high schools teach from the point of view that most of their students will *not* go to college, we cannot expect, as we

did in the early years of this century, that the average high school graduate is ready to build up his scientific knowledge from his earlier courses. We must instead consider his high school training as of relatively little importance. Remembering the inadequacy of this training, our committee felt that it was better to assume that our students, in common with those of other colleges, had had a type of training that was not specifically designed to fit them for science instruction on the college level. Those who were fortunate enough to have had an unusually good quality of instruction on the secondary level might take an exemption examination, but the majority should take a prescribed college program in science which would provide one part of an education which is to be both inclusive and balanced.

Science cannot, of course, occupy the whole of the college curriculum, and the faculty limited the time for natural science to fourteen semester hours. Such an amount may seem too small to the teacher of science, too large to the teacher of French, yet it should enable the instructor to present an adequate view of the world of science without specialization in any one field. Naturally, a number of us in the sciences felt that not enough time was given to what we regarded as the most important of human developments; at the same time, some of our colleagues thought that the time given to science could be spent much more wisely in considering the glory of Greece and the grandeur of Rome. The compromise in allotted time forced upon the committee the question of selection of material.

Astronomy, biology, chemistry, geology, and physics were all included in our curriculum because of their importance in providing a unified body of knowledge about natural phenomena, from the infinitesimal electron to the infinite galaxy, from the microscopic to the macrocosmic.

#### *Organization of science courses*

If one attempts to teach science as a single unified body of knowledge, separate departmental courses must be abandoned for an interrelated presentation of materials selected from various sciences. Perhaps such a selection may be criticized adversely as making up "just another general science course." Such a criticism is invalid, for the fourteen semester hours

allow sufficient material of college level to be given, particularly if care is taken in the selection of this material and it is correlated rather than duplicated.

As to academic credit, the work of the first year carries four credits each semester, while six credits are allowed for the entire second year's work. In the first year, there are three periods of informal lecture, one quiz period, and one two-hour laboratory period each week. In the second year, there are two lecture periods and one quiz period, and occasional field trips. No definite time is assigned for trips, but these can be scheduled easily since there are no regular classes on Wednesday afternoons.

There has been much discussion of the proper order of presentation of the several sciences. Some feel that physics should precede chemistry; others believe that all sciences should be developed from the infinitesimal to the infinite, while a third group prefers to begin with the study of the earth and to follow this with an examination of its components and of the universe which encompasses it. Since the committee was eager to include as much relevant material as possible in the prescribed fourteen semester hours, it felt that ease of presentation and clarity would be improved by not following too strictly the "logical sequence" theories of science instruction. The order thought to be best was chemistry, biology, geology, physics, and astronomy. The work was divided into three units: Natural Science I, primarily concerned with chemistry, Natural Science II, which drew most of its material from biology, and Natural Science III-IV, a single unit of a year's length, in which geology, physics, and astronomy were dealt with. Such an arrangement does not, however, imply that chemistry and only chemistry is the subject matter of Natural Science I. Although in at least one of the "logical sequence" theories, physics should precede chemistry, the committee felt that through the study of chemical reactions, several laws of physics could be stated more clearly. For example, the instructor might move directly from the examination of oxygen and hydrogen to a consideration of the gas laws. Likewise, through the study of chemical reactions, the various types of energy would become apparent.

Since the study of inanimate matter appears to be antecedent to that of living matter, chemistry can be used as a

background for biology. When osmosis, for example, is examined in the latter science, no extended explanation is necessary. Instead, reference is merely made to the discussion of this subject in chemistry. By avoiding needless repetition, more time may be given to additional concepts, a procedure that would be impossible if the courses were entirely unrelated and each had to be fully developed by itself.

In determining the proper order of astronomy, geology, and physics, the committee realized that chemistry and biology offered an excellent background for these three sciences. Geology, followed by physics and astronomy, seemed a useful teaching sequence, especially since the material itself is so interrelated. In the discussion of winds in geology, for instance, much information usually presented in physics can be given, and with greater clarity and meaning. Once departmental barriers are broken down, it is amazing to see how many relationships exist and in how many different contexts material can be presented.

Insufficient laboratory space and instructor time made it desirable to have half the students begin with chemistry and the other half begin with biology. This division of time does not negate the sequential arrangement of material since close cooperation between the two departments has eliminated independent treatment of the subjects.

Another practical consideration also influenced the committee in deciding on a variable sequence. The departments of biology and chemistry require that majors take certain courses in an order which necessitates an early determination of the order of the basic courses as well. A candidate for the degree of bachelor of science in chemistry may elect chemistry the first semester of the freshman year, and by postponing biology, may continue with chemistry the second semester. The student wishing to major in biology may, in the same manner, place most of his emphasis in that field. Since most of the students taking the natural science sequence are neither biology nor chemistry majors, the teaching loads of the instructors are not varied to any great degree because of this factor.

#### *Natural Science I*

In determining the materials to be presented, the committee kept constantly in mind the aims previously stated for

science. In Natural Science I the concept of matter, the kinds of matter, and the states and properties of matter are the starting points. To some degree this semester's work is treated chronologically, for after a discussion of the Aristotelian theory of fire, air, earth, and water as the kinds of matter, the student is gradually led to the alchemical period. He learns that during this period natural phenomena come to be observed critically, the laws of science develop through inductive reasoning, and an art is thus transformed into a science.

The study of two gases, oxygen and hydrogen, gives experimental evidence from which generalities can be drawn. With the laws known and extra data available, theories and hypotheses arise. From the study of these gases, the kinetic theory is developed. The two gases reacting chemically to produce water introduce the two kinds of matter, elements and compounds. The student then begins to observe various types of chemical activity. With knowledge of chemical laws and of the properties of matter, he can make deductions and applications to practical life.

The similarities of the elements are studied by means of the periodic system which is shown to evolve from the work of Döbereiner, Newlands, and Mendelejeef. Then the valence concept of the binding of atoms to form molecules of compounds is developed. This is related to the classification of electrolytes and nonelectrolytes and the study of solutions.

Through an examination of the classification of crystals it becomes clear to the student that external appearance usually is evidence of internal arrangement. This knowledge of crystals becomes exceedingly helpful when the various minerals are discussed in geology. The student learns that Moseley, Rutherford, Becquerel, and others discovered that atoms are composed of protons, electrons, and neutrons, and that as Lewis and Langmuir, Bohr, Debye, and others postulated, each element differs from every other in kind and arrangement of its constituent particles. To complete the picture of the composition of matter, radioactive disintegration and atomic fission, leading to the chemistry of the atomic bomb, are explained. Steps in the manufacture of those commercial products for which our area is noted are explained in preparation for field trips to manufacturing plants. Finally the chemistry of carbon and silicon compounds is discussed. The carbon com-

pounds are studied with particular emphasis on biological processes. The silicon compounds, particularly the silicates, lend interest to and information of value for the study of rock formations in geology.

### *Natural Science II*

The second-year science course is the study of things that are living or that have lived in the past. The student is introduced to the nature of living substance through the study of moving protoplasm in protozoans and single-celled plants. The movement of protoplasm in the cells of living Elodea leaves is observed microscopically as an example. An introduction to the different kinds of living things and an awareness of the variety of plants and animals is made by visual examination of the various phyla. Trips are made to the museum to see specimens of invertebrates, to the zoo where living vertebrates are observed, and to the conservatory where firsthand acquaintance with the plant kingdom is made. Adaptations of living things to their environment (fresh water, the sea, forests, meadows, deserts) and the variations within that environment are discussed. Further enlightenment on the adaptability of living things is provided through motion pictures and trips to the museum where studies are made of ecological groups of plants and animals in a Florida jungle, an Arizona desert, a Mt. Rainier Alpine valley, a Pennsylvania swamp, and a Pennsylvania forest and meadow.

The relationships between living and extinct things are taught by a comparison of living plants and animals and those represented by fossils of different ages. Again the museum is utilized as a laboratory. As a basis for his comparative study, the student sees the matrix of rock, the process of removing the fossils, and the process of assembling them.

He is also taught to realize that his own species is subject to the same natural laws that govern the lives of other species. To do this, plant and animal nutrition, including photosynthesis, fat, protein, and carbohydrate metabolism, absorption, circulation, respiration, waste elimination, sensation, and co-ordination are studied. In the laboratory various demonstrations and experiments are performed. The student dissects a pig as a representative mammal. In this area, as in Natural Science I, every attempt is made to have the student see the

relationships of what he is currently studying to what he has finished and to what remains to be studied the following year. He studies biology, but he does so in the perspective of unified science.

With the completion of the first year's work, the basic concepts concerning the building blocks of the universe, inanimate and animate, have been presented. Plant and animal life and nature's laws governing and controlling life have been given studious consideration. The student is now ready for Natural Science III-IV, where he turns his attention to the earth, its physical laws, and the universe of which it is a part.

### *Natural Science III-IV*

The introduction to cosmic science is made through a brief study of the earth's place in the universe. This is limited to a short survey of our own solar system and more particularly to the influences of the sun on the earth and moon. Such topics as the earth's rotation and revolution, gravitation, the season and equinoxes, the moon's phases, and eclipses and tides are considered. This is followed by specific study of the earth's hydrosphere, atmosphere, and lithosphere. After an examination of the water cycle, surface waters and their erosive influences are considered. Shore lines, flood planes, meanders, levees, and deltas are included.

The nature of the earth's atmosphere, its components, their distribution in clouds and fogs, the manner in which they are affected by zones, temperature, and pressure—all are a part of the section devoted to climate and weather. Through the charting of weather maps, cyclones and other storms are traced along time intervals. Planetary circulation of winds and seasonal winds are examined, followed by a study of the influences of winds and ice, and the soil erosion and glaciation resulting from them.

The various hypotheses concerning the formation and early history of the earth are points of conjecture preceding the classification of the rocks. The study of metamorphism as realized in folds, fractures, dips, faults, and earthquakes follows. The use of seismographs is explained. The time scale of the five eras from the Archeozoic to the Cenozoic is treated with particular reference to the geological history of North America.

The physical causes and effects of geological phenomena are given thorough consideration. Whether it be the mechanical force of a glacier eroding a valley, an electrical force generated in a storm, or heat from a volcano, the physical aspects are introduced. In some cases the discussion includes a description of physical energy even though a more complete treatment of the subject will follow.

In order to provide understanding of the speed of planets, electrons, and rays of light, the units of motion and force are defined and Newton's laws of motion are elucidated. The gas laws influencing Joule's work on heat are reviewed, and the mechanical equivalent of heat with emphasis on its commercial importance is stressed. The electrical nature of matter, the passage of a current of electricity, and the mutual presence of an electrical field and a magnetic field are evaluated for their effect on generators, transformers, photoelectric cells, electrical cells, and electrodeposition of metals. Wave motion is studied as the basis of sound and light which are then analyzed and considered in terms of their practical significance.

In the latter part of Natural Science III-IV, the earth's place in the universe is studied. Careful attention is paid to the earth as an astronomical body, the celestial sphere, the measurement of time, the laws influencing the stars, stellar mechanics, the classification of astral bodies, and the identification of constellations. Considerable help is provided in this section of the course through the availability of the Buhl Planetarium, one of the best in the country. The two years' work is summarized and concluded with a discussion of man's place in the universe.

### *Laboratory*

Laboratory work, though limited to one year, plays a very significant role in the entire program. It is through concrete experience, analysis, and experimentation that the student comes to think about the uniformity of nature and its amenability to measurement and classification. Through the laboratory the student comes to appreciate the care and discrimination necessary in scientific procedure; here he recognizes the true meaning of the scientific attitude. Laboratory work is occasionally made a part of the second year's program,

but here the emphasis is more upon demonstration and field trips. Every attempt is made to use available visual aids, for more effectively than lectures these take materials out of the book and put them in the mind. The college film library, containing more than fifteen hundred items, is an invaluable aid in visual education work in science as well as in many other fields.

#### *Reading materials*

A syllabus for each course is furnished to the student at cost. Mimeographed materials containing brief outlines of the lectures, the daily assignments from the text and the laboratory manual, a list of collateral readings and special questions and problems for classroom discussion are supplied. The syllabi serve as nuclei for a summation at the end of the several semesters, as well as before the general examination in the senior year. The time ordinarily required to make daily assignments is used profitably at the beginning and end of each semester to emphasize the aims and purposes of the course and to summarize the content and relate it to previous work, and work to come.

#### APPRAISING THE RESULTS

The method of examining students is important. The students are quizzed orally and by ten-minute tests each week. Generally three or four hour-length tests are given throughout the semester and a three-hour test occurs at the end of each semester. In compliance with the regulation for graduation, each student must take general examinations covering the entire basic curriculum at the end of the first semester of the senior year. Included in this examination are questions covering the two years of science, with emphasis on scientific interrelationships as well as on the place of science in the entire general program.

The weekly quiz periods are more than class sessions for testing purposes. These sessions aim for discussion and clarification and it is probable that the best teaching is done during these hours. Each quiz section is small enough (15-25 students) to give everyone a chance to participate. The students in one quiz section are also in the same laboratory section. This is another means of creating familiarity and insuring the instructor of an opportunity to deal individually with the

students in a friendly atmosphere. Our experience has indicated that lecture sections may have as many as a hundred students, since the room is so arranged that every student in a group of this size can see the demonstration desk easily.

### THE TEACHER

It is extremely important that the entire teaching faculty, whether in science or in other fields, should be thoroughly acquainted with the methods and problems of presentation. They should know the syllabi of the courses, for informal discussion of these syllabi by the faculty as a whole is extremely helpful, even essential. The opinions of our colleagues in economics and mathematics and German aid us in outlining a living science program.

The chief difficulty experienced in such courses is in finding teachers who are dynamic and not perfunctory. This requires that faculty members must first want to do the job because of its significance; they must then prepare themselves to do it. To get faculty members previously trained for such work is extremely difficult. The load rests heavily on those who have been trained as specialists, but it is amazing to see how enthusiastic they become once they are introduced to a correlated program. It is only through a conviction of the superiority of these new general education courses over the conventionally patterned ones that faculty members can achieve the dynamic teaching essential to the success of such a heavily prescribed program, but with enthusiastic, intelligent teaching, any student resentment of "required courses" vanishes, once the reasonableness of the requirement is made clear. This imposes a continuing obligation upon faculty members to repeat aims and purposes at the beginning and end of courses, and even in between.

### EMPHASIS ON ACHIEVEMENT

One point should be reiterated. The emphasis is, and must be, upon achievement rather than upon the "taking of courses." There is no defense for duplicating materials in the process of education. Exemption examinations are available for students who may already know the material. If they can pass these exemption examinations and can ultimately pass the general examinations in the senior year, this is all that Pennsylvania College for Women, or any other

college, should ask. If the principle of achievement is accepted, the problem of the transfer student as well as the freshman with a strong secondary school or post-high school program is easily managed.

The benefits of such a unified science program are numerous. The natural world comes to be understood as complex but marvelously intertwined in its relationships. The student gets a more complete knowledge of science and what it does in civilization. He gets a broader understanding of the sciences and their respective practical significance. He acquires a common body of knowledge with his fellow students, and the principles of scientific procedure and thought become more pointed and meaningful. The faculty is not without its gain, too, for scientists with varied backgrounds are brought together and artificial barriers are broken down.

This program is not merely a two-year sequence *about* science. There is a considerable amount of factual material to be covered, of course, but this has been carefully selected to give the student an understanding of the basic concepts of science. Attention is paid to the social functions of science and its place in the growth and development of Western civilization. The scientific method as a way of thought and action is emphasized over and over. We are eager that our students be literate about the entire scientific enterprise; that they develop persistent scientific habits and attitudes.

No one can accurately presage the scientific requirements that the world of tomorrow may ask of students now in college. No one can properly evaluate the worth of our program until those who have taken it have been at work for ten or twenty years. Certainly it would be foolhardy for us to say that we have a truly complete answer to the question of what makes up a good undergraduate science sequence. But we do look forward with confidence to the answers which the future will bring us.

## **Physical Science in General Education, Colorado State College of Education**

**I**T WOULD seem reasonable that the very meaning of the term, *general education*, would imply that it does not vary with the ultimate vocational objective of the student but rather with his level of development and experience. Thus, general education for the prospective teacher and general education for the premedical or prelegal student should not differ because of the variance in the chosen field of concentration. Variations should arise from legitimate differences in opinion as to what constitutes general education on the various levels of education achievement and from differences in individual students' previous experiences, both in and out of school.

Colorado State College of Education considers its primary purpose the training of professional educators, principally teachers and school administrators, for all levels from the nursery school to the college and graduate school. Its program of general education has been established in terms of the thinking of its faculty and administration, but the program is one equally defensible for students who do not intend to be teachers. Evidence that this is the present point of view of the faculty is found in the fact that the list of required courses in general education as published in the latest year-book is the same whether the student is preparing to teach or to enter some other profession.

The present required courses, from which no graduating student is excused except in certain cases of demonstrated proficiency in a given area, include the following (with the quarter hours of credit allowed for each):

By William L. Dunn, acting chairman, Division of the Sciences, Colorado State College of Education.

The Basic Course in Humanities	12
Introduction to Physical Science	4
Introduction in Biological Science	4
General Psychology	4
Elementary English Composition	4
Personal Hygiene	4
Family and Social Relations	4
American Life and Institutions	4
Contemporary World Civilizations	4

With the exception of the last three, which are taken as a social science sequence in the sophomore year, these courses are normally taken in the freshman year. For a number of years one quarter has been devoted to the physical sciences and one quarter to the biological sciences.

The course in the biological sciences which will not be described in this paper consists essentially of five units entitled as follows: (1) The Physical Basis of Life, (2) Human Reproduction, (3) Heredity, (4) The Basis of Human Behavior, (5) Immunity.

#### THE PHYSICAL SCIENCE COURSE

Though no one who believes in general education would be willing to omit the study of science from the curriculum, the question usually is one of determining what kinds of courses will best fit the needs of students not majoring in the sciences. All introductory courses in science are of the "survey" or "general" type in a sense, since they bring together material from many more highly specialized areas. Thus, a science major takes "general chemistry" or "general zoology" as beginning courses. Where one should cease to unite concepts from more specific areas in the pattern of education is a matter of opinion. The tendency now is to bring this integration into the college curriculum in the program of general education.

The argument that a "survey course" lacks academic respectability in contrast to the traditional departmental courses in the various sciences has no doubt been justified in many cases, but that they must, of necessity, be shallow is hardly tenable. The fusion of botany and zoology into the college biology course has long been acceptable, and comparable courses in the physical sciences are now being taught with equal success. It is true that a departmental course is easier

to teach, since a general course requires more varied background and more delving into material less familiar than the teacher's area of specialization. Such an experience is, however, salutary in that it enriches the teacher's fund of ideas and can result in a better job of teaching his specialized courses.

Another drawback to the interdepartmental course is the widespread practice, particularly in universities and larger colleges, of advancing a teacher only on the basis of research rather than on the basis of good teaching. This is no doubt due to the fact that it is easier to evaluate a person in terms of the papers he produces than in terms of the less tangible results of good teaching, and also because many universities like to be known for their direct contribution to the store of human knowledge, even if the quality of teaching must suffer. Teaching only in the field of one's specialty allows more time for research; thus, one is discouraged from centering his attention on courses in general education and from spending the time necessary to do a good job of teaching.

The successful divisional course also requires more time of teachers in conference with each other, since each teacher is not, by reason of his training and experience, an expert in all of the material. Such a sharing of knowledge and ideas should have a wholesome effect on the quality of teaching.

Some of the advantages of a general course in the sciences are:

1. It is possible to demonstrate the "oneness" of scientific laws throughout all branches of science, showing that the division of subject matter is an academic one based upon convenience.

2. Certain concepts of wide application can be stressed in a general course, but they are likely to be lost in favor of specialized material in one science if the usual introductory courses for majors are utilized for general education purposes.

3. Since subsequent courses are usually not based on the general course, its content can be determined by student interest, teacher and student evaluation of material, and suitability for purposes of general education, rather than upon what will be needed in a course which follows.

The purposes of an interdepartmental science course may be broadly conceived as follows:

1. To develop in the student an understanding and an appreciation of the value of the scientific method, not only as it is applied in the solving of problems in science but in other situations including those in the student's experience;
2. To give to the student some knowledge of a few important generalizations in science which will enable him to understand more fully the natural phenomena occurring around him, thus increasing his enjoyment of life;
3. To enable the student to see more clearly the relationships between science and technology and the happenings in his social and political world;
4. To help the student to read intelligently and critically scientific information intended for the layman;
5. To help to free the student from the blindness of prejudice and superstition which hamper the full development of the equitable social order that is a part of our cultural heritage, but which yet awaits its fulfillment.

There are essentially two approaches to the general course in the sciences.<sup>1</sup> One is the organization of the course around certain principles of science and the other is the organization around certain carefully selected problems. The first is sometimes criticized for laying too much emphasis on "facts" and for trying to cover so much material that the student is confused by its enormity. It has the advantage of familiarizing the student with considerable information. The second type of course is criticized for its omissions, but is considered to have the advantage of stimulating greater student interest and probably of bringing about a more thorough understanding of scientific method.

At the Colorado State College of Education, the course at present is essentially of the "principles" type, although individual teachers attempt to inject the methods of problem solving into their class work. The course has undergone extensive revision since its beginning about 1930. This is due partly to the experience gained by those teaching the course and partly to new teachers with different ideas as to what the course should include. No attempt at complete coverage is made. Rather, certain understandings, considered important, are selected, and

<sup>1</sup>Sidney G. French, "Science in General Education," *Journal of General Education*, I (April 1947), 200.

an effort is made to teach these as well as to bring about a realization of their importance.

The work is divided into three units. The following is a brief outline of the course.

### OUTLINE OF COURSE

#### I. Matter and Energy

- A. Introduction (a discussion of the sun as the primary source of the earth's energy)
- B. The direct sources of energy available to man
- C. The kinds of energy
- D. The modern concept of atomic structure (includes a discussion of the experimental work upon which the modern picture of the atom is based)
- E. The relationship between matter and energy
- F. Radioactivity
- G. Nuclear bombardment
- H. Nuclear fission
- I. Control of atomic bombs
- J. Constructive uses of atomic piles

#### II. Chemical Energy

- A. The kinetic-molecular theory of matter
- B. The states of matter
- C. Physical and chemical properties of matter
- D. The formation of chemical compounds
- E. The rates of chemical reactions
- F. Acid-base phenomena
- G. Oxidation-reduction phenomena
- H. Some important organic compounds

#### III. Magnetism, Electricity, and Radiant Energy

- A. The phenomenon of magnetism
- B. Static electricity
- C. The conversion of chemical energy to electrical energy
- D. The conversion of mechanical energy to electrical energy
- E. Induced currents
- F. The conversion of electrical energy to mechanical energy and heat
- G. The electromagnetic spectrum
- H. Electronics

A variety of materials is used in the course. The students purchase a basic text which was written by the teachers who started the course. This text, used primarily as a reference work, is supplemented by an adequate supply of pamphlets in the library dealing with the topics under discussion. Some of these pamphlets may be obtained free from manufacturers. Reference books, a list of which will be found at the end of

this statement, are also placed in the reference room in the library.

Mimeographed study guides, listing study questions, references, and outlines of the topics to be studied, are given to each student. Study guides also direct the student's attention to certain important features of the films which are shown during the regular class meetings. Pictures and charts are posted on the bulletin board and exhibits are arranged to illustrate the topics under current discussion. Demonstrations are also provided during the class period to take the place of individual laboratory experience, now impossible because of lack of space.

At the beginning of each quarter, a pretest, the equivalent of a final examination, is given to each person registering in the course. This test has two uses. The first is to excuse from the course those students whose knowledge indicates that they would profit more from an elective than from the general course. About 5 percent of those registering for the course are excused. They are persons who have had several science courses in high school or who are particularly interested in science. The second purpose is to provide a basis for measuring the improvement of individual students through the quarter.

Classes are limited to about fifty students and the sections are not brought together except for examination. This means that each group has contact only with its particular instructor. There is some argument for having a given topic presented to a large group by an expert in that area and then having a discussion of the topic in smaller groups, but it has been the belief of those who have taught this course here for many years that this plan is less desirable than keeping the sections separated at all times for presentation of material. The class periods combine some lecturing with class discussion and the answering of questions raised by the students.

Teachers of varied backgrounds conduct the general course. Recruiting teachers from the various areas of specialization has the advantage of providing an expert whose opinion is of value when considering a point related to his major field of interest. If possible, at least one person from each of the major fields of preparation—chemistry, physics, geology, and astronomy—should participate in teaching such a course. Ob-

viously, the more widely diversified is the training of each outside his major field, the better prepared he is for the job. Our course has been taught by staff members whose major fields are botany, physics, chemistry, zoology, mathematics, and science education, two or more of these fields being represented in a single quarter. Frequent conferences between teachers provide a measure of uniformity and serve to level out the differences in emphasis, which the individual instructor might be prone to give to a certain topic. Exchange of ideas and knowledge is also facilitated by discussions between the teachers.

It should be said that there is not complete agreement among the teachers as to what should be the nature of the course. All believe that the time is too limited. Some think that integration of the general physical and biological science courses could profitably be made by fusing them into one course, but this has not been attempted. One reason, no doubt, is that some teachers, who would feel adequate for one, would not feel equal to the combined course because of serious gaps in their own training. There is also a feeling that some laboratory experience would be valuable, but this would be very limited, if it were attempted at all. At present there is not adequate space, and laboratory work is experienced only in a vicarious fashion through watching demonstrations. With anticipated increased facilities it may be possible to expand the course in this direction.

Although the organization and the subject matter included are not uniformly agreed upon, discussions between the teachers and with the students make continued improvement certain. Some feel that the problem approach is by far the superior attack; others, that the present method is the more desirable. The course is in something of a continuous state of flux, but, at the same time, maintains a definite continuity from one quarter to the next. This is indicative of the desire, on the part of those teaching it, to see it develop.

The conviction that the general education of college students, insofar as it is the direct responsibility of science teachers, is best served by integrated courses in the sciences rather than by departmental courses has led the Colorado State College of Education to embark upon a program of preparing teachers for these fields. Graduate students, majoring in the sciences, can now register for a course which deals with course organization,

methods of teaching, use of visual aids, and similar matters pertaining to the general courses in the sciences. Observation of and some participation in one of the classes in general science on the college level is a part of the program. We are confident that the program will help to fulfill a great need.

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# **Science Introductory Courses for General Education in the University of Louisville**

**T**HE TWO introductory (survey) courses in the Division of Natural Sciences—Introduction to the Physical Sciences and Introduction to the Biological Sciences—had their inceptions in the College of Arts and Sciences in 1933, together with Introduction to the Social Sciences (Problems of Modern Society), History of Civilization in the Social Sciences, and the Humanities Course (literature, art, music, and philosophy). These courses along with freshman English composition make up the basic required courses for general education.<sup>1</sup>

Each introductory science course is a one-semester (17 weeks), three-credit, nonlaboratory course. Each course is complete to the extent that it is neither prerequisite to nor integrated with any departmental course or courses in the college. A student may begin in either course and follow with the other. Classes meet three times a week for fifty-minute periods. Various visual aids are used in lieu of a laboratory.

These courses are primarily for freshmen who plan to major in divisions other than the sciences. They also serve as general education courses leading to an associate of arts degree. Though primarily for freshmen, sophomores may enroll with the permission of the divisional chairman. A student may be excused from the physical science requirement by completing an equivalent course in astronomy, chemistry, geology, or physics, and from the biological science requirement by a basic course in the biology department with a minimum grade of C, or by passing the science part of the freshman entrance examinations above

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<sup>1</sup>J. J. Oppenheimer, "The General Courses in the College Program," *School and Society*, LI (1940), 518-22.

the fiftieth percentile. Should a student, after completing an introductory science course, desire (through change of major) to take a basic laboratory course in a department, he is allowed credit for both courses, but if he has previously obtained credit in an equivalent laboratory course, he cannot receive credit for the introductory science course.

In the beginning, departments were allocated a definite number of class periods to present their subjects. As a result, students pursued the beginning course in each department without the advantage of laboratory experience or visual aids. Placing the emphasis upon traditional subject matter in a condensed form and racing against time to present it resulted in confusion and discouragement on the part of both students and instructors. This led to a realization that an entirely different philosophy and approach was necessary.

Two fundamental and very important things had to be determined: (1) scientific needs of individuals in order to live happily and successfully in the modern world and (2) scientific concepts and principles to be employed in developing instructional materials in introductory courses at the freshman level. It was also recognized that each course should be complete in itself and not in any way prerequisite for advanced courses in science.

A period of planning and experimentation began. Frequent meetings were held with members from the various science departments and the groundwork laid for a more careful selection of subject matter, better integration, use of visual aids, and the building of study material in the form of syllabi. It was decided that the introductory physical science course and the introductory biological science course should each be given by a single instructor, a plan which resulted in better coordination than had previously been obtained with several more specialized persons who divided class periods among them.

The success of the courses depended upon the selection of the instructors with broad training and interests. General training in astronomy, chemistry, geology, and physics was necessary for one; in botany, zoology, and their subdivisions for the other. Other prerequisites were an understanding of students and zeal to work with them at this level.

As these changes were made, both students and instructors became more satisfied, but other difficult problems arose.

Suitable references and study materials were scattered throughout several libraries and a satisfactory all-inclusive textbook for the physical science course could not be secured.

The biological science course has been fortunate in having Austin R. Middleton as its instructor for several years. He has developed many new ideas on teaching materials, and has compiled a syllabus and workbook to meet more effectively the special needs of the course.<sup>2</sup> Though the introductory course in physical sciences has made less progress in this respect, because several instructors have spent only a year or two with the course, improvement is now occurring under Charles W. Prewitt.

An abundance of visual aids is a must in science courses without laboratory at the freshman level. We have been very fortunate in obtaining the necessary visual aids in the form of motion pictures, lantern slide and opaque projecting equipment, demonstration apparatus, charts, models, and so on. Part of the visual aids have been supplied from the Division of Natural Sciences budget and part on loan from the different science departments. The course could be improved by some type of a science museum or workshop where students in their leisure hours could observe or experiment with materials pertinent to the courses.

It is a mistaken idea that a large number of students can be handled effectively at one time in introductory courses of this type. We have experimented with classes of more than a hundred students and with small classes. If large lecture classes are supplemented by small discussion and quiz groups, a fair return in student achievement is obtained. We have found, however, that about forty students is an ideal size class. This number may be seated close enough to the instructor to see clearly the demonstrations; it is large enough to develop a spirit of competition between students and to retain the enthusiasm of the instructor, yet small enough for personal attention in class discussion and question answering. Smaller classes lack competition and enthusiasm necessary for maximum achievement.

Obtaining and determining valid student needs in the fields of science are difficult and require continuous effort. Habits,

<sup>2</sup>A. R. Middleton, *Syllabus of the Biological Sciences*, University of Louisville, 1942; *Workbook in the Introduction to the Biological Sciences*, Hobson Book Press, (1947).

precollege training, practices, interests, concerns, attitudes, abilities to employ critical thinking and skills vary and change, and so do the needs. Many media supply information on needs and each should be explored. Needs were selected from information obtained through health inventories developed by the Cooperative Study in General Education,<sup>3</sup> Biology Interest Inventory developed locally,<sup>4</sup> local health organizations, questions and suggestions by both undergraduate and graduate students, and experiences and judgments of instructors in both science and nonscience departments. The health inventories were so constructed that information could be obtained on (1) practices (desirable and undesirable), (2) knowledge about health, (3) interest and concerns, (4) attitudes and points of view, (5) ability to employ critical thinking, and (6) skills in appraising the relevance and reliability of sources of health information. These problems were related to personal appearance, diet, nutrition, operations of the body, physical and chemical hazards, reproduction and heredity, and personal health problems. Biology Interest Inventory was given only to students in the beginning biology course. Local health organizations, both city and county, were asked to list what they considered the most important health needs. Notes were taken on questions asked and suggestions made by students during and after class, relative to needs.

Faculty members in the social sciences and humanities as well as those in the various science departments were asked to list what they thought were the most important scientific needs applicable to students at this level. Needs vary so greatly that it is impossible in the time allotted for the course to consider individual student needs. However, the majority of needs, particularly those derived from inventories, fall into a pattern. By compiling them from all sources, sorting, and frequently elaborating, those needs thought most important and urgent were selected and used in developing the courses.

In many cases the instruction to meet the needs selected could be easily delegated to one course or the other, but such concepts as those in the use and conservation of energy, matter,

<sup>3</sup>*Cooperation in General Education* (Washington: American Council on Education, 1947), pp. 142-45.

<sup>4</sup>P. A. Davies, "Student Wildlife Interests, School Science and Mathematics, XLI (1941), 425-28; "College Students Interest in Biology," *Journal of Educational Research*, XXXVI (1942), 7-15.

and health required careful discrimination in order to prevent unnecessary duplication and loss of time.

### INTRODUCTION TO THE PHYSICAL SCIENCES

#### *Aims*

1. To know a fund of information about astronomy, chemistry, geology, and physics.
2. To understand the scientific method and acquire practice in its application.
3. To develop scientific attitudes.
4. To know the major economic aspect of the physical sciences.
5. The establishment of an appreciation of man's accomplishment in discovering scientific facts and principles.
6. To be able to read and to discuss intelligently scientific topics of interest to the layman.
7. To understand the role of science in modern civilization and to be aware of the problems that may be created and solved by it.
8. The enjoyment of science as a leisure activity.
9. To acquire, through knowledge of the history of the physical sciences, a greater appreciation of the contributions of science.
10. To know the important sources of reference materials in the physical sciences.
11. To know the relationship of science to other fields of learning.

#### *Principles*

Space does not permit the publication of the entire list of physical science principles used in developing the course, so a few samples were selected at random. Some of the principles in the main list were taken from publication No. 2810 of the Progressive Educational Association, and the remainder developed locally.

1. All substances are made up of small particles called molecules, which are alike in the same substance but different in other substances.
2. Energy cannot be created or destroyed but may be changed from one form into another.
3. Energy is involved in all chemical action.

4. All matter is made up of atoms and molecules which are in constant motion.

5. The physical state of matter depends on the speed of motion of the molecules composing it and upon the attraction of the particles for each other.

6. Every body in the universe continues in a state of rest or uniform motion in a straight line unless acted upon by some external force to change that state.

7. The work obtained from a machine never exceeds the work put into it.

8. Light travels in a straight line in a medium of uniform density.

9. An electric current is directly proportional to the electromotive force and inversely proportional to the resistance.

10. The chemical activity of a substance depends on the number of electrons revolving around the nucleus of the atom.

11. Substances that dissolve in water will cause the resulting solution to boil at a higher temperature and to freeze at a lower temperature than pure water.

12. If the same pressure is maintained, the volume of a gas is varied directly as the absolute temperature.

13. A reduction of air pressure accompanies an increase in altitude.

14. Earth processes proceed in endless and recurring cycles, and change is one absolute function of the universe.

15. Strata of rocks occur in the earth's surface in the order in which they were deposited, except in the case of overthrust faults.

16. When elevations or depressions are created, the elevations are attached by agents of erosion and materials are carried to the depressions where sedentary rocks are formed.

### *Concepts*

The following concepts were selected as the important ones for developing the course:

Atom	Magnetism	Solutions
Diastrophism	Matter	Sound
Electricity	Motion	Space
Energy	Radiation	Time
Heat	Sedimentation	Vulcanism
Light	Solar system	Weathering

### *Course content*

#### **Unit I. Introduction**

Definition of science. Divisions of the field of science. Organization of the course. Material dealt with in the course. Relation to other fields. Reasons for studying physical sciences.

#### **Unit II. Scientific Method**

Science as a method. Historical development of the methods of science. Inductive and deductive reasoning. Influence of scientific method on other fields. Scientific attitudes.

#### **Unit III. Structure of Matter**

Modern concept of the structure of matter. Definitions of compound, molecules, elements, atoms, protons, electrons, neutrons. Early Greek concepts. Concepts of the alchemists. Seventeenth-nineteenth century concepts. Development of modern concepts in twentieth century. Atomic energy. Radioactivity. Isotypes. Atomic energy tools. New elements. Atom splitting. Manufacture of the atom bomb. Use of the bomb. Control of the bomb. Peacetime uses of atomic energy. Present status of atomic energy.

#### **Unit IV. Radiant Energy**

Energy in the universe: importance, definition, classification, transformation and conservation, exhaustible and inexhaustible sources. Study of radiant energy in past. Development of corpuscular and electromagnetic theories. Forms and uses of radiant energy. Light. Correct lighting for study. Color. Spectroscope.

#### **Unit V. Electricity**

Static electricity. Early and modern concepts of magnetism. Generator. Transformer. Motor. Electricity from power plant to consumer. Batteries. Uses of electricity.

#### **Unit VI. Chemistry**

"Better things for better living through chemistry." Historical development of chemical knowledge. Electrolysis. Law of chemistry. Solution. Crystallography. Steel and alloys. Organic chemistry. Synthesis and use of representative compounds. Chlorophyll. Propaganda in advertising chemical products.

#### **Unit VII. Heat**

Heat and molecular motion. Historical use and concepts of heat. State of matter. Measurement of heat. Transference of heat. Heat and the human body. Control of heat. Humidity. Fuels. Heat engines. Heat in the home.

#### **Unit VIII. Sound**

Wave motion. Production and transmission of sound. Musical sound. Resonance. Acoustics. Radio. Vacuum tubes.

#### **Unit IX. Geology**

Utilitarian values. Theories as to origin of earth. Formation of earth. Inner layers. Crust. Diastrophism. Vulcanism. Erosion. Period of earth's history. Conservation of soil and natural resources.

**Unit X. Astronomy**

Man's place in the universe. Astronomy in history. Laws of motion. Motions of the earth. The moon. The sun. Solar systems. Stars. Star systems. Relativity.

**INTRODUCTION TO THE BIOLOGICAL SCIENCES*****Aims***

1. To know a fund of general information about biology.
2. To know, in a general way, the sources of valuable reading material in biology in relation to general education.
3. To know the economic aspects of biology.
4. To know the interrelationships of biology to other fields of learning.
5. To acquire a knowledge of and an ability to use the important biological principles.
6. To develop an understanding of scientific methods and scientific attitudes.
7. To develop an awareness and appreciation of the natural laws.
8. To develop an increased appreciation for the presence and the beauty of nature.
9. To acquire, through knowledge of the history of the development of biology, a more intellectual appreciation of the contributions of biology.
10. To develop a range of interest in the science of biology.

***Principles***

The following principles were selected at random from the large list used in developing the instructional materials in the course:

1. Either directly or indirectly, energy-containing foods come from green plants, because of their ability to "carry on" photosynthesis.
2. Organisms are essentially energy mechanisms, and are designed for the reception, storage, and release of energy.
3. Protoplasm is the one essential constituent of every living thing, and upon its peculiar properties the life of the organism depends.
4. Germ plasm passes in an unbroken, continuous stream from one generation to another, while somatic plasm, an expression of germinal characteristics, arises anew each generation.

5. Organisms arise from similar pre-existing organisms, and results from scientific investigation indicate that not even the smallest bits of protoplasm arise by spontaneous generation.

6. The cell is the unit of structure and function in all organisms.

7. There is a constant integration of the various structural and physiological components of an organism so that it can function as an active unit.

8. From the lower to the higher form of life, there is an increasing complexity of structure and this is accompanied by a greater division of labor.

9. Organisms are classified according to their natural relationships, and those which are of similar origin are grouped together.

10. In a specific environment over a sufficient period of time there occurs a succession of organic forms which continue until a balance or climax is reached.

11. The distribution of organisms is conditioned by the use of favorable highways and the absence of barriers.

12. The environment acts upon living things and living things act upon their environment.

13. The plants and animals in a given environment are mutually interdependent.

14. Higher organisms undergo more or less orderly changes from the beginning to the end of life.

15. Variation is a universal phenomenon among living things.

16. All organisms have been derived from pre-existing organisms and resemble their ancestral stock more closely than do other organisms.

17. Every expressed character in an individual is the product of the interaction of hereditary and environmental factors.

18. Coordination in higher animals is brought about through the agency of nervous tissue and chemical coordinators (hormones).

19. Organisms at the beginning of the food chain are smaller and more numerous than at the end.

### *Concepts*

The following concepts in botany and zoology were selected as the important ones around which the course content was developed:

Cell	Energy conserva-	Interrelationships
Classification	tion	Morphology
Ecology	Evolution	Physiology
Economic	Genetics	Protoplasmic
Embryology	Historical	Reproduction

*Course content***Unit I. Introduction**

The origin of biology. The definition of science. The scientific method. Why biology is a science. The subdivisions of biology. Use of the techniques of the physical sciences in biology. The ultimate search of all sciences.

**Unit II. The Kinds of Organisms**

Why organisms are classified. Origin of the method of naming organisms. Binomial nomenclature of Linnaeus.

**Unit III. Classification of Organisms**

The plan of classification. A simple key to the animal kingdom. Classification of plants.

**Unit IV. Structure of Organisms**

Protoplasm History of the name "protoplasm." The essential characteristics of protoplasm. Manifestations of vitality. Physical agents and protoplasm. The cell theory. The physical structure of protoplasm and the cell. Cell division. Mitosis. Osmosis. Organisms composed of cells. Generalized and specialized organisms. Division of labor.

**Unit V. Distribution of Organisms**

Distribution of plants. Factors of prime importance in plant distribution. Comparision of the temperature zones of the northern and southern hemispheres. Classification and localization of the original natural vegetation of the world. Types of plants. Distribution of animals and plants.

**Unit VI. Problems of Organisms**

Food, water, light, heat, and carbon synthesis. Synthesis of fats and proteins. Uses of minerals. Types of nutrition. Soils. Elements needed by plants. Difference between soil and its parent material. Part played by organic material in maintaining soil fertility. Soil texture. Soil water. Soil structure. Elements of weather. Climatic controls. Types of climate. Ecology. Vegetation. Plant successions. Plant associations.

**Unit VII. The Importance of Organisms to Man**

Surplus food manufactured by plants. Plant secretions and excretions. Fiber plants. Forest products. Food plants. Parasites of plants. Animal parasites. Human parasites. Microorganisms and pathogens. Immunity. Special means of prevention of spread of disease. Definition of public health terms. Economic importance of animals to man. Passage from food gathering to food producing.

**Unit VIII. Structure and Functions of the Human Body**

The body as a machine. Activities of the human body. The seven functions necessary to the continued life of the individual and the species. Functions of circulation. Plan of the circulatory system. Lymphatic circulation. Breathing. Preparation of the air for entrance into the lungs. Respiration. Excretion. Circulation through the kidney. Functions of the kidneys. Accessory organs of elimination. Digestion. Nutrition. Coordination in the body. Chill, infection and disease. Treatment of diseases. Reproduction. Growth and development of the embryo. Birth, childhood, adolescence, maturity, and senescence of the human body. Internal secretions and development.

**Unit IX. Genetics and Eugenics**

Mitosis. Maturation. Fertilization. Mendelian inheritance. Factor inheritance. Determination of sex. How hereditary determiners exert their influence. Eugenics.

**Unit X. Evolution**

What evolution means and what it is not. Growth of the evolution idea. Difference between evolution and the casual explanations of evolution. Essential points of Darwin's theory. Human evolution.

### EVALUATION

We realized that any program of evaluation, to be effective, must be of service to the course, students, and to the instructors. We wanted to know how well the course or any major part was meeting the requirements selected for it, that is, science in general education at the freshman level. Experience had shown that in order to obtain this information, the instruments of evaluation must focus on broad objectives, needs, principles, concepts, and so on. Results from testing of units or weekly quizzes over small areas did not yield sufficient breadth of information to be of much value. Well-constructed midsemester and final examinations gave the information desired. We have tried both essay and short-answer types of examinations and have abandoned the essay for the short-answer type. Although it is argued that essay tests are better media for integration and valid instruments for determining needs in remedial English, we believe that well-constructed, short-answer examinations are just as effective in measuring integration and that remedial English needs may be determined in other areas of the evaluating program.

At the end of the semester, students are asked to express their opinions concerning how well the course answered their scientific needs, whether it increased or decreased their interest and appreciation of science, the amount of required reading,

and whether there was an adequate amount of visual aid. Much valuable information was gained through consultations with students who had previously taken the course, and enough time had elapsed (at least one semester) so that they could judge the course as a whole.

As the student is our chief concern, we want to know his progress at frequent intervals throughout the course. For this purpose we have found that weekly quizzes or unit tests, both essay and short-answer types, are of great value. They are constructed in such a way that only a few minutes are required to answer them and they can be quickly scored and returned at the next period for self-evaluation and discussion.

Through these tests and examinations and from class discussions and enthusiasm on the part of students, the instructor has an index as to the success of the course, data for its improvement, and a valid basis for final grades.

## **General Education in the Physical Sciences at Kansas State Teachers College**

**K**ANSAS State Teachers College at Pittsburg requires for the degrees of bachelor of arts, bachelor of science, and the bachelor of science in education a certain minimum experience in communications skills, the humanities, and in the natural and social sciences. For purposes of administration the courses in these areas are grouped in the divisions of language arts, natural sciences, and social sciences.

Partly because of instructional difficulties, our general education courses are not so broad and comprehensive as those in some colleges and universities. We are, however, moving in the direction of greater breadth and integration of subject matter. Thus, although in communications the oral is still separated from the written work, a comprehensive course is planned for this area.

The other courses especially designed to meet general education requirements are Introduction to Literature, History of Civilization, Introduction to the Fine Arts, General Mathematics, General Biology, Fundamentals of Physical Science, and Introduction to Social Science. Students may choose either literature or the fine arts in the language-arts area, but in the natural science division at least two of the three courses must be elected, and no field which was not taken in high school may be omitted. Although students are not as a rule permitted to elect the general course in the field in which they are majoring or minoring, exceptions are made in the cases of literature and the history of civilization.

By William H. Matthews, associate professor of physics, with an introduction by Ernest Mahan, dean of instruction, Kansas State Teachers College, Pittsburg, Kansas.

### FUNDAMENTALS OF PHYSICAL SCIENCE

The course Fundamentals of Physical Science is offered for college students who do not intend to make science their life work and have entered college with little or no training in that field. Specifically the purposes of the course are to orient the student in the physical science fields, to give him an appreciation of scientific method, and to develop an understanding of the contributions of the physical sciences to the solution of contemporary problems. As a comprehensive presentation of the relationships and widely used application of the physical sciences, Fundamentals of Physical Science seeks to furnish a basis for correct scientific thinking, and to impart knowledge of present-day science and industry and their social implications. In any such course the aim is to present all principles in language simple enough for the uninitiated. A textbook is chosen which presents the material in such orderly and understandable fashion that the instructor can devote the greater part of his time to lectures, demonstration, and leading class discussion.

Students normally elect the general education course in physical sciences in their second year. The subject is covered in one eighteen-week semester in which three hours a week are allotted to regular classwork (lectures, demonstrations, discussions, and reports given by students) and four hours are devoted each week to laboratory periods.

Responsibility for the selection and presentation of the subject matter for the entire course is vested in one individual. He is free, however, to use such members of the staff as he wishes for the presentation or discussion of various phases of the work of the course. Thus one member of the physical science staff may be asked to present his unusually clear introduction to the periodic table, while another will be regularly scheduled as a lecturer on climatology. Following any such lectures delivered by individuals brought in for that purpose, the instructor reviews the material presented by the visiting lecturer and stresses those portions of it that have a logical place in the general scheme of the course.

### PRESENTATION OF MATERIAL

At the first regular meeting of the class each student receives the assignments to the chapters of the text, with the

order in which they will be studied and the time allotted to each. He is also given samples of the types of tests that will be used (approximately fifteen short examinations are given during the semester, corrected, and returned to the student) and made to understand that the questions on such tests will be used in part on the final examination. In this same initial session the student receives a forty-one-page outline of the course. Among other things the outline contains specific instruction concerning the preparation of the notebook which is taken up at midsemester and soon returned with constructive criticism. It is taken up again two weeks prior to the end of the semester and graded. This mark counts for two-fifth of the course grade.

#### *The notebook*

The seven chapters of the student's notebook are listed below, with the type of required material indicated.

1. Textbook Questions and Problems. Here the student includes the answers and solutions to questions and problems appearing at the end of the chapters assigned in the regular textbook.

2. Laboratory Experiments. The notes in this section should be complete enough to indicate the student's understanding of the experiments observed or performed in the laboratory.

3. Classroom Demonstrations. The student should record here observations that reflect his understanding of the scientific principles demonstrated during lecture table experiments, an important means of amplifying textual material.

4. Special Demonstrations and Experiments. During the entire semester the student is urged to discover experiments and demonstrations that can be performed with low-cost apparatus or materials found at home. This chapter might include, then, notes on: boiling of water at low pressures and temperatures, toy balloons and static charges, the hiccup bottle, surface tension experiments (using a glass of water and a handful of nails), observing sun spots through a developed photographic film, and crushing a can by means of air pressure. There is room here, too, for newspaper clippings or notes on information or experiments selected from daily newspapers, periodical literature, books, and other outside sources.

5. Related Materials. From time to time the student will come across material, ideas, facts, and so on closely related to

the field of physical science, also to be recorded in the notebook. To give the student a clear idea of the type of entry that should be included under this heading, the course outline furnishes the following examples of statements and problems:

#### *Statements*

A person who weighs 180 pounds on the earth would weigh about thirty pounds on the moon.

The water going over Niagara Falls has its temperature raised .21 of a degree F. Heights have been measured by this method.

If you pay ten cents for a flashlight battery, you are buying electricity at the rate of about fifteen dollars per kilowatt hour.

Soft, black, shiny, oily graphite is the humble sister of the flashy diamond.

Carbon has more compounds than all the other ninety-one natural elements combined.

A gallon of sea water contains 1/100 pounds of magnesium.

In its compounds, oxygen makes up one-half of the earth's crust, about nine-tenths of the weight of water, and a large part of all animal and vegetable matter.

The sun is a star but not one of the largest.

Should Arcturus suddenly go dead, we would still receive light from it for forty years.

It would require from 400,000 to 500,000 full moons shining on the earth to provide the amount of light received from the sun.

#### *Problems*

A billboard advertisement reads: "A gallon of this gas contains enough energy to lift the Goddess of Liberty three and one-half feet." What is the weight of the Goddess of Liberty?

If light has a velocity of 186,000 miles per second, how fast would one have to run around a square building in order to see himself just disappearing around the first corner?

How many pounds of carbon are there in a ton of limestone?

6. **Scientists and Their Contributions.** This section of the notebook is reserved for the names and nationalities of outstanding scientists of the past and present, with a brief description of the contribution made by the latter to the development of the physical sciences. Included are persons discussed in class and laboratory periods and others whose names are discovered by the student in his reading beyond the regular text. Nobel Prize winners in the fields of physics and chemistry are listed since the year 1901, and the student at the end of the semester will have from fifty to a hundred entries, depending on his interest and reading.

7. **Class Reports.** As indicated above, each student makes one or more classroom reports during the semester. He in-

cludes notes on his own and his classmates' work in this section. The reports themselves cover a wide variety of topics, of which the following are examples: types of telescopes, plastics, abrasives, natural and synthetic rubber, electron guns, common rocks and minerals of this locality, isotopes, oil refining, uses of the vacuum tube, and instruments used in the study and forecasting of weather.

### *Laboratory and demonstration*

The methods used for the laboratory portion of Fundamentals of Physical Science are not those commonly employed in the physics or chemistry laboratory, as seen in the presentation of energy manifested as light, described below.

Before any laboratory assignments are made, the topic is covered during lecture or class periods, and the students are supplied with direction sheets describing twenty-four laboratory experiments and observations relating to light. Some of these exercises are completed within a short time; others require up to fifteen or more minutes. The students are grouped by fours and then required to perform the experiments and operations. The apparatus is mounted and ready in five different rooms (two of them are darkrooms). With the instructor and his assistants on hand to provide help where needed, the various groups of students move from one experiment to another until they have completed all the assignments. The following observations are regularly made in the study of light:

Note the color change in a heated body with the increase of absorbed energy.

Sketch a continuous spectrum as pictured on a laboratory chart and another to show bright light spectra for each of four elements. Obtain the wave length corresponding to each line and record it on the drawing. In the report explain the Fraunhofer lines.

Observe the spectrum formed when light is passed through a glass prism.

Observe the spectra and orders formed by gratings containing different numbers of lines. Observe also the spectra formed by simple gratings, one an ordinary lined photographic plate, the other a piece of closely woven cloth.

Using the diffraction grating, study the spectrum of at least two gas-filled luminous spectrum tubes. Record the number and positions of the lines in the spectrum for each tube and describe and indicate the use of the spectroscope.

Note the colors obtained from sunlight by selective reflection and transmission and also by the interference of light at cracks in calcite crystals and by reflection from thin films.

Observe the interference of light through a small slit, through a pinhole, at the contact of two pieces of glass, and at surfaces that are optically flat.

Measure candle power of lamps by means of Bunsen and Jolly photometers.

With a foot candle meter compare the intensity of light at a fixed distance from a 100-watt carbon lamp, a 100-watt clear type C lamp, and a 100-watt frosted type C lamp. Repeat the test for the 100-watt clear type C lamp after placing the lamp in a diffusing bowl.

Using the foot candle meter, make a light survey of a room.

With argon lamps and other ultraviolet ray sources, study the fluorescence of rocks, oils, dyes, uranium salts, paints, and other materials.

Use a solution of quinine sulphate to get a measure of ultraviolet light associated with sunlight.

Study fluorescent lamps by observing lamp data, intensity of light, flicker and color, theory of operation, auxiliary apparatus, and efficiency.

Use the stroboscope to determine speeds of rotating bodies and the frequency of alternating currents.

The experiments carried out to find the index of refraction and to study the nature of polarized light are rather more complicated.

#### *Index of Refraction*

A copper penny is placed in a hydrometer jar which is filled with water. The student measures and records the length of the water column and then looks from the top of the jar through the water at the coin. At the side of the jar he places his finger at the level at which the coin appears to be. After measuring this distance from the top of the jar he can calculate (from the two measurements) the index of refraction of water.

The student thrusts a meter stick into a large plastic water-filled bowl—at an angle of less than 90 degrees—and observes how the stick seems to be bent.

A lighted electric lamp is enclosed in a box which has only a pinhole opening through which the light can leave the box. Over the pinhole is placed a rhomb of calcite. Since the crystal is double refracting, two rays are observed from the pinhole. The crystal is then rotated to demonstrate which is the ordinary and what the extraordinary ray.

#### *Polarized Light*

Under guidance of the instructor, light is polarized and analyzed by means of glass plates. With a polaroid analyzer the student observes that the transmitted and reflected light from the plates is polarized but in different planes. A polariscope is then set up, with nicol prisms to polarize and analyze the light. Another polariscope is made with two pieces of polaroid. Strains in glass and in plastic materials are observed in polarized light, as are thin films of mica and cellophane.

In other experiments, optical benches, lenses, and screens are set up in different rooms so that students can take data relating to object distance, image distance, and the focal length and magnifying power of a lens.

Seven simple experiments are performed with relation to the eye. These include the blind spot, the actual position of a shadow on the retina, stereoscopic vision, persistence of vision as to color and to intensity of light, color blindness, and the Snellen eye chart. Three different types of microscopes are examined and reported upon with respect to operation, the uses of the objective, the eye piece, and how magnification is obtained. A careful study of the camera is made to discover the relations and sizes of images and objects, the distances of images and objects, and to obtain information on relative aperture.

During the period allotted to the topic ("light" in this instance) all laboratory equipment relating thereto remains assembled in the rooms mentioned. Except for one or two sets which are left for individual study, it is replaced at the end of that time by apparatus for study of the next topic. In the case of the light experiments, the apparatus used for the demonstration of fluorescence and phosphorescence is made available—along with part of the equipment used in polarized light experiments—as long as the students show any interest in the subject.

Students are encouraged to test anything which daylight observation leads them to believe will glow in ultraviolet light, or again to check ordinary daylight from day to day with a test tube filled with a quinine sulphate solution. Those who manifest unusual interest in polarized light and the polariscope are urged to check for strains in panes of glass set in frames. They do likewise with products of the glass blower and with pieces of fabricated plastic and other like objects. They are shown also how to determine roughly the index of refraction of opaque objects.

The laboratory assignments discussed above are typical of those made in other subjects of the course except that they are rather more extensive in character and thus receive approximately twice as much time as assignments on other topics. This is explained by the fact that the first assignments constitute an introduction for the student. He is making his

initial acquaintance with laboratory methods and requirements. During this first period also the instructor takes special pains to select the best students as group leaders, to note and discourage any tendencies toward carelessness on the part of some, and to discover which students will be most likely to require his personal attention and help during the remainder of the course.

Closely related to the laboratory work are the demonstrations given in regular class periods. Usually at least one demonstration is presented in each of the three lectures. To be effective, every demonstration must be a success. If there is any thought that a given piece of apparatus will not produce the desired results, that particular instrument or piece of equipment is not used. The same policy holds with respect to equipment in the laboratory as well, for while a major student may conceivably profit or learn something from the failure of equipment (through instruction as to repairs and adjustment), the development of laboratory or repair techniques is not one of the aims of the course.

### *Use of mathematics*

While Fundamentals of Physical Science is by no means thought of as being preponderantly mathematical, it does not avoid problems requiring the understanding of and ability to use mathematics. Students must expect to be concerned with such operations as calculating the number of miles in a light year, converting a centimeter of length into Angstrom units, determining the cost of power required to light a football field or that used in a given appliance—for example, a ten-watt lamp burning continuously over a thirty-day period. It is felt that students in their second year of college should not find it too difficult to determine the weight of a rock of known volume and density or the number of pounds of zinc in a ton of zinc ore. Nor does the instructor hesitate to derive from energy considerations the equation: "the shortest wave length from an x-ray tube is equal to approximately 12345 divided by the impressed voltage," or to relate in an equation Faraday's electrolysis constant, Millikan's value for the charge on the electron, and Avogadro's number. He makes it clear, however, that he derives such equations in class primarily for the purpose of leading to an appreciation of the work of these

and other scientists. It is not the aim of the general education course to require complete mastery of techniques used in each of the various branches of a science.

#### OBJECTIVES AND CONTENT

Something has already been indicated as to the content of the physics portion of the course. Before a discussion of other fields is attempted, it will be well to consider for a moment certain aspects of the course as a whole. In the construction and operation of a course in physical science some problems can never be completely solved. Or rather, some phases of the work give rise constantly to new problems. This is true, for example, of the content of the course and of the time element, where allotment of lecture and laboratory periods to various subjects and adherence to a schedule are both important considerations.

The material that goes into a general course on physical science must have meaning for those who have no background in science and provide them with an understanding of science and scientific methods. It must show them what science is and how it operates. Foremost among the instructor's objectives is his desire to arouse and sustain the interest of his students—something that is close to being a thrilling adventure for them. Subject matter must at every step be highly organized and presented with real skill and understanding so that the student not only comprehends what is under discussion but is inspired to further reading and experimentation in the same field.

The question of how much time to devote to each phase of the work is not an easy one. Experience has shown that the most equitable and successful division allots six weeks to physics and chemistry respectively and three weeks each to geology and astronomy. At the beginning of each new subject or field, the instructor must remind himself of the necessity of showing the same enthusiasm for this portion of the work as for that just completed. He is successively a teacher of physics, of chemistry, of geology, and of astronomy. And he is at all times a teacher of all of these subjects, or of physical science as a whole. In each instance he has a wealth of material that must be drawn upon intelligently. In each instance he must show the relationships existing between the

various branches of science. Thus when he moves from physics into chemistry, the instructor stresses the carry-over value of atomic theories, atomic weights and numbers, of oxidation, combustion, gas laws, electrolysis, crystallization, surface tension, density, specific gravity, distillation, and Brownian movement. The place of these laws and principles in chemistry must be as understandable to the student as their place in physics.

### *Chemistry*

To return to the subject content of the three remaining fields of the course: in chemistry the student is introduced to and soon learns about the properties, detection, and relationships of acids and bases and salts. The chemists' shorthand methods of writing and balancing equations become clear to him and furnish further evidence of the exactness of chemistry as a science. Because he is called upon to prepare many of them, compounds are no longer a mystery to the student. In the six weeks given over to chemistry he receives a carefully controlled introduction to material that embraces chemistry associated with living things, matter associated with chemical energy, methods of cleansing, true and apparent solutions, and a study of such compounds or chemical products as textiles, cellulose, and plastics.

The instructor shows wherever possible the application of the principles and laws of physics and chemistry to the other fields in the course.

### *Geology*

Special stress is laid upon the table of geological ages and local geology with its relationship to the periods of the table. Kansas State Teachers College is situated in the lower part of the Pennsylvanian formation, with the population of the immediate vicinity located in ten towns along the formation known as the outcrop of the Weir-Pittsburg coal seam, a formation largely responsible for the settlement of the district and the establishment of many of its industries.

To the southeast a few miles the Pennsylvanian has been completely erased by erosion, and the Mississippian formation is clearly exposed, in which the Bartlesville sand outcrops. This formation yields large quantities of oil, not here but in various Kansas fields. Lead and zinc ore and many rocks

quite different from those found in the Pennsylvanian are mined in the Mississippian formation. Within a distance of fifty miles the Pennsylvanian is overlapped by the Permian with its economic products such as salt, clay shales, building materials, and gypsum. The physical and economic geology of these formations, their common rocks and minerals, and economic products all receive special attention in classroom reports and laboratory study, with maps and survey reports as they are needed. The student thus gains a fair idea of this branch of science and a knowledge of the geological formation of one particular locality. Further, he should know the proper procedure for acquiring such information about any other region in which he may later become interested.

### *Astronomy*

The subject of astronomy is introduced with a lecture by an expert who discusses the work of the astronomer. Later the same staff member or expert visits the observatory with the class and explains and demonstrates the ten-inch equatorial, refracting telescope. At various times during this part of the course the department of visual education presents films concerning the moon, the earth and its motion, the solar family, exploring space and the universe, and other related topics. Textbook chapters supply material on the sun and moon and the stars, on planets and other bodies, on eclipses, and on the earth as a planet and a clock. In the classroom attention is directed particularly to star maps and the location of some of the better-known constellations—Ursa Major, Ursa Minor, and Cassiopeia, to mention a few. Astronomical definitions are compared with geographical definitions (magnitude, the poles, celestial equator, the zenith, the horizon, an hour circle, the meridian, a vertical circle, altitude and azimuth), and the astronomer is shown to use many of the instruments with which the student has by this time become familiar: telescopes, mirrors, cameras, spectroscopes, and the thermocouple. The astronomer's application of laws and principles discussed in physics and chemistry is made clear in discussions of the relation of temperature to color, of density, Newton's laws, centrifugal force, types of spectra, and Doppler's principles.

Laboratory assignments require members of each group to measure sizes and distances by triangulation methods, to de-

termine the position of the sun at different times during the day, and to measure diurnal motion. Each student thus develops his judgment in identifying star magnitudes, in locating of sun spots, and by the intelligent use of star maps. From the beginning the astronomy phase of the general course has proved exceptionally interesting to both students and instructors.

#### *New scientific developments*

Another problem to be reckoned with in a course on the physical sciences concerns new developments which are too important to be ignored and must therefore be included somewhere in an already overcrowded schedule. To suggest the treatment they receive in Fundamentals of Physical Science, two examples (developments in the field of atomic energy and the plastics industry) are given here.

One lecture period and one laboratory are devoted to a brief introduction to the subject of atomic energy. When students have completed their assignments on the atom and its radiation, the instructor enlarges upon this beginning by means of a lecture and the use of charts and other devices to explain various questions concerning atomic energy: the percentage of uranium 235 contained in uranium ore, methods of separating the U 235, fission, chain reaction, the carbon pile, the manufacture of useful isotopes, and atomic power as a by-product of a plant that manufactures radioactive materials. Finally, the instructor endeavors to insure the student's understanding of key words as they apply to the atomic bomb: critical size, tamper, modulator, half life, transmutation, and disintegration.

Material related to the manufacture of plastics has been so arranged that in the one lecture and one laboratory period given to this subject the class participates in the development and molding of two well-known cast plastics—cresol formaldehyde and phenol formaldehyde. The students compare three commercial plastic glues and combine urea and formaldehyde to make a resin. Molding powders are made from the resin by adding various fillers and, after being heated, are then molded under pressure. Samples are compared for flexural and tensil strength and hardness. Then experiments are made to discover the effects of accelerators and retarders and to

learn why solid acids and lubricants are added to the material. Flow sheets of many popular types of plastics are copied and incorporated as notebook material.

### APPARATUS

A balanced program for a comprehensive course in the physical sciences demands an unusually large amount of apparatus. Some of this, of course, is the type used in any physical science laboratory; other pieces (some of them simply laboratory applications of ordinary commonplace objects) are constructed by the instructor and his assistants or contributed by the school shops. In the last few years the acquisition of war surplus materials has made it possible to direct some of the regular budget funds to the purchase of spectacular pieces which would not be considered under normal circumstances.

Although the laboratory apparatus mentioned above is essential, many important and meaningful experiments can be conducted without recourse to equipment of this type. One such is that carried out during the study of acoustics. When the students have acquired some knowledge of the speed of sound, of reverberation time, echoes, dead spots, sound reflecting surfaces, and absorbing materials, they undertake a survey of the college auditorium. A sketch is made of the room, and the members of the class move quietly to various designated stations. Here they listen to the instructor as he speaks or reads at the speaker's position on the stage and note on their sketches how poorly or well he can be heard. When all observations have been made, the recorded data are discussed by the group as a whole. In this manner the students discover which areas are acoustically satisfactory, which are not so, and the conditions that result in such differences. Suggestions as to corrective steps are entered with other data in the students' notebooks.

### TEACHERS FOR GENERAL COURSES

General education courses are among the most difficult to teach, and Fundamentals of Physical Science is no exception. On the instructor's part it demands a great deal of time and the most careful organization; from the institution it requires an unusual amount of equipment and room space. The difficulties are, of course, compensated for by the wide range

of interests (found in any general education course) and the new developments to be expected in the sciences. Of no less importance to those in charge of the course is the progress of the students. Indeed, one of the instructor's major concerns is to make this progress evident to the students, primarily by means of short objective tests which furnish conclusive proof to them that they know something about the subject, that they are improving their methods of thinking and acquiring a considerable amount of worthwhile information.

If at the end of the semester the student looks upon the experience as primarily difficult and dull, the instructor has failed in his task. The instructor who succeeds will have created in his students a desire to continue reading in the field and to find pleasure in the understanding and discussion of things scientific. Through the years that the course has been offered the majority of students have shown increasing interest in its content and satisfaction in it as an introduction to the physical sciences.

## The Physical Sciences in General Education at Antioch College

THE ANTIODCH design for liberal education provides for a "curriculum" that includes three equivalently valued opportunities for individual growth: the academic course of study, a succession of cooperative work experiences, and participation in the democratic processes of improving the college community. Although these simply cannot be wholly discrete experiences in the life of Antioch student or teacher, their increasingly effective integration is consciously and vigorously sought.

The academic course of study divides about equally for the A.B. candidate between a program of general "required courses" and an unusually individualized program of "field courses," these latter increasingly related, as the student progresses, to his cooperative work experience and his vocational objectives. For the B.S. candidate the division is unequal; the program of "required courses," necessarily including basic sequences in technical science and mathematics courses, comprises more than two-thirds of the total in academic credits.

### THE REQUIRED COURSE PROGRAM

The required course program is explicitly designed to provide "the common ground of a liberal education . . . the knowledge and attitudes all educated men should share if they are to build a cooperative society that makes possible increasingly greater capacities in greater numbers of people."<sup>1</sup>

Not all but most of the required courses are classified into five areas as outlined below:

By Oliver S. Loud, associate professor of physical sciences, Antioch College.

<sup>1</sup>A. D. Henderson and Dorothy Hall, *Antioch College: Its Design for Liberal Education* (New York: Harper and Brothers, 1946), p. 67.

**Communications:**

Current Reading and Writing	5 credits
Mathematics for Modern Life	5 "

**Physical science:**

Physical Sciences I	5 "
Physical Sciences II	5 "
Introduction to the Earth Sciences	5 "

**Life science:**

Introduction to the Life Sciences	10 "
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**Social science:**

Early Man and His Civilization	5 "
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Foundations of Western Civilization or Modern European History	5 "
India, China, and Japan	5 "

American Government or American Civilization	5 "
Principles and Problems of Government	5 "

Economic Principles and Practice or Fundamentals of Economics	5 "
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**Humanities:**

The Arts and Man	5 "
Landmarks of Western Literature	7 "

Invitation to Philosophy or Ethics	5 "
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This outline makes it clear that Antioch College takes the general education component in liberal education seriously. For more than twenty years, it has experimented with this unusually heavy requirement. Two convictions are growing: (1) that this emphasis upon the "common ground" of liberal education is warranted; (2) that this general education component in the academic curriculum should extend *throughout the college years (and, indeed, the postcollege years!) parallel with the program of field courses.* As the years have gone by,

rigid sequences in the required course program have been dissolved in the interests of greater flexibility in planning individualized programs of study. And alternative courses in the social science and the humanities areas are specially designed for younger and maturer students separately.

Recently it has been recognized that the array of required courses frequently adds up to a rather fragmented general education experience. Within each division, experimentation with integration has been organized. The next step is seen to be the establishment of a faculty-student committee of equivalent significance to the several divisions themselves and charged with the re-examination of the required course program as a whole, conceivably to recommend to the Curriculum Committee certain proposals for achieving a larger integration still, an integration that the divisions, working however diligently on their own problems, cannot realize.

#### THE REQUIRED PHYSICAL SCIENCES COURSES

It is now possible to turn to the physical sciences as part of the general education component in the Antioch curriculum. The unusual requirements for the A.B. candidate in this area—since the B.S. candidate typically substitutes the technical sequences for the required courses in the physical science area—have distinguished the Antioch curriculum for more than twenty years and reflect the continuing faculty evaluation of the role of the physical sciences in the modern world.

Until recently there have been three separate five-credit courses: general chemistry, general physics, and introduction to the earth sciences. This latter course survives as an eminently successful required course, frequently cited appreciatively by Antioch seniors and graduates. It integrates the sometimes separate disciplines of astronomy and geology into a basis for studying the history of the earth and of life as affected by the changing physical environment. The economic, social, and philosophical implications of the material are explored. Informal lectures and conferences are supplemented by required reading, laboratory work, and field observations. The course is, at the same time, the introductory course, prerequisite for the advanced technical courses taken by those few students who elect to major in geology.

## THE NEW TWO-YEAR SEQUENCE INTEGRATING CHEMISTRY AND PHYSICS

Beginning in the fall of 1947, the required courses in general chemistry and general physics have been replaced by a two-year, ten-credit sequence in the physical sciences, in which there is no longer any attempt to separate these two closely related disciplines. This limited experiment in integration is the principal responsibility of a teacher whose entire professional concern is with the teaching of science in general education. (There is a possibility, not yet explored, that the earth sciences will come to be included in a more intensive, two-year, fifteen-credit sequence in the physical sciences.) An account of the emerging design of the present course, attempting the integration of chemistry with physics, is here presented.

So far as chemistry and physics are concerned, Antioch College has drawn what has been increasingly recognized by educational leaders as a valid and necessary distinction between the objectives of a course for the general student and the objectives of a course for students beginning to major in a scientific field. It is extremely dubious whether a single course can effectively attempt both sets of objectives. (A consequence of this curricular decision to provide two different kinds of elementary course, it should be noted, is that the objectives of science in general education, valid alike for technical and nontechnical students, have to be pursued less overtly by the technical student and throughout the whole sequence of technical courses. It may be that there are better ways of resolving this difficulty. One way is presented at the very end of this article. A supplementary way might be to provide a *terminal integrating general education seminar* for the B.S. candidates, staffed not only by physical science, but also by philosophy and social science teachers.)

At Antioch, a syllabus is required from the instructor of each course. Among other specifications, the syllabus must state the objectives of the course as the instructor conceives them and as, perhaps, the student can accept them, at least in part, as his own. These stated objectives of the new physical science sequence might profitably be quoted in full. They represent a drastic abbreviation of the fuller statement of objectives produced while the design of the course was first under consideration. In their comprehensiveness, the objectives are

very ambitious. In a very crucial aspect that will be emphatically pointed out, they are unusually and very properly modest.

The objectives of the physical science sequence are:

1. to assist the student to prepare for
  - 1.1 continuing self-education in the physical sciences as they may prove to concern him
  - 1.2 demonstrating sufficient achievement in the understanding of the physical sciences to meet the general requirement as defined for the Antioch degree
2. to begin to clarify for the student
  - 2.1 some of the basic vocabulary, techniques, concepts, and current hypotheses of the physical sciences
  - 2.2 both the social context for, and the internal processes involved in, the maturing of the physical sciences, historically and currently
  - 2.3 the continuing social function of the physical sciences and the necessary conditions both for effective scientific work and for realizing in the lives of people the advantages made possible by scientific developments
3. to guide the student toward using the physical sciences consciously for the purposes of
  - 3.1 more intelligent living as an individual, in a family
  - 3.2 more intelligent participation, as a citizen, layman in science, in the making of public policy, planning the solving of social problems
  - 3.3 more intelligent effort in the design of a philosophy that is both personally satisfying and socially effective
4. to reveal to the student some of the connections between the physical sciences and other disciplines, so that he is assisted to integrate his learning
5. to provide a good time for the student, because of his
  - 5.1 learning in association with others
  - 5.2 demonstrably achieving some of the objectives that he has accepted
  - 5.3 successfully combining genuine effort with a reasonable leisureliness
  - 5.4 feeling free from fear of failure or from any other unnecessary hindrance to learning.<sup>2</sup>

The essential modesty of these objectives lies in their representing a deliberate abandonment of any mistaken ambition on the part of the teacher to use the student's required enrollment in the course in order "to teach him the science that he needs to know," "to cover the so-called fundamentals,"

<sup>2</sup>Oliver S. Loud, *Introduction to the Physical Sciences*, mimeographed syllabus, Antioch College, 1948, p. 2.

"to mend the gaps in his science background," or "to equip him with a basic scientific literacy." The emphasis is not upon producing an educated individual but rather upon assisting the individual to recognize and accept the continuing, life-long task of self-education, a task which he can only begin (or advance) during his college years. Each year at Antioch, the teacher of physical science in general education teaches less and there is impressive evidence that his students learn more! Granting that there must prove to be a point of diminishing returns to such an unconventional trend, it seems, nonetheless, to be clearly the way of wisdom!

In the many discussions whereby the physical science division reached the decision to recommend to the general faculty that the new two-year sequence in physical science be tried, there seemed also to be fairly good agreement on a number of rather fundamental propositions. To state some of these propositions simply will rather directly distinguish the physical sciences sequence at Antioch from analogous offerings at many other colleges. We find, of course, that the precollege experience in physical science, even for the superior students that Antioch is privileged to admit, is shockingly impoverished. We find, too, that the general student, like many a technical student, is seriously handicapped in his approach to the physical sciences by deficiencies in his communicative skills (the use of English and of mathematics). But some of our working hypotheses concerning the kind of physical sciences course we want to build place us quite clearly on the frontier of current educational experimentation.

Thus, we are convinced that the integration of chemistry and physics into a single course should proceed upon some other basis than that of reviewing in turn the several physical sciences. We reject the superficial survey type of course whether taught by one teacher or by a succession of specialists from the respective disciplines. We do not want a descriptive course, reviewing or attempting to convey the findings of science. The course should be, we feel, a course in science, not "talking about" science. On the other hand, it should not be an introductory technical course, more or less adapted to the nontechnical student. It should not be an easy course, demathematized or eliminating laboratory investigation. Surely, we argue, it should be as exacting as any

worthwhile course must be and differing not so much in difficulty as in central objectives from other courses.

Because this experiment is at present limited to an attempted integration of chemistry and physics, it is stipulated that the course, while pointing up the social and philosophical applications of physical science, remain unmistakably a physical sciences course and avoid becoming some kind of social science or humanities course. The practice has been initiated, therefore, of validating the exploration of social and philosophical issues by having representatives of those other divisions of the faculty participate as guest discussion leaders at appropriate points in the course. Thus the philosophy professor has discussed with us "the place of Newton in the development of Western thought;" the economics professor has discussed with us the issue identified as "energy resources and social policy." This collaboration represents merely the beginning of what might be done toward integration in the curriculum.

It is sometimes acknowledged that education is supposed to affect the participants, teacher and student, profoundly—to stir them, to change them significantly, not only intellectually but morally as well. Now if one asks how a required science course might be expected to stir deeply a non-technical student—or for that matter a scientist-in-training—a possible answer might be: by impressing the student indelibly with what is often called the spirit of science. A sensitive discussion of the educational difficulty of this task can be found in J. Robert Oppenheimer's recent lecture at the Massachusetts Institute of Technology.<sup>3</sup> He asks, "Are there elements in the life of the scientist which need not be restricted to the (unusual!) professional, and which have hope in them for bringing dignity, courage, and serenity to other men?" He describes the character of the scientific discipline and reminds us that "it is very different to hear the results of science, as they may be descriptively or even analytically taught . . . and to participate even in a modest way in the actual attainment of new knowledge." He suggests that the "teaching of science is at its best when it is most like an apprenticeship" for "there is something irreversible about ac-

<sup>3</sup>J. Robert Oppenheimer, "Physics in the Contemporary World," MIT Lecture, reprinted in the *Bulletin of the Atomic Scientists*, IV (March 1948).

quiring knowledge; and the simulation of the search for it differs in a most profound way from the reality."

If one agrees with Mr. Oppenheimer in these judgments, then—whether one teaches technical or general students—one can hardly expect in any proximate future to become complacent about the teaching procedures he is employing. Just how does the physical science sequence at Antioch propose to become a "course in science rather than about science?" to convey something of the "spirit of science?"

It must be acknowledged that the equivalent of an apprenticeship in the scientific investigation of unsolved problems has not been surely identified. (A possible clue is suggested in the closing paragraphs of the article.) But it can be contended that the challenge is taken seriously and that, meanwhile, two approaches are being employed. One is very similar to the recent effort of President Conant of Harvard University, who selected certain crucial controversies in the history of science to analyze, with the hope of revealing the dynamics of scientific work in the careful reconstruction of these controversies, communication by communication, critical experiment by critical experiment. The other is very similar to the emphases on scientific method made in good technical courses: critical review of the design of the experiment, discussion of the theory of measurement, demonstration of the dimensions of the terms in the equations used for calculation, stress on the responsible use of significant figures, interpretations of data in terms of establishing relationships among measurable variables, and scrupulous analysis of sources of error.

These aspects of scientific procedure are dealt with, first in group or demonstration, and then in individual laboratory investigations. One final kind of effort is made: the assignment of "original" laboratory investigations requiring leisure, ingenuity, trial and error, and successive refinements of the devised techniques. Such simple problems as determining the solubility of a salt or the factor(s), other than "g", affecting the period of a pendulum have proved promising for this purpose.

One final point concerning the theory of design of a physical sciences sequence for general education might be made before describing the Antioch course as it has thus far come

to take its shape. Such courses around the country are as often as not constructed upon the basis of an energetic conviction concerning the fruitfulness of some single, major emphasis. Perhaps it is not necessary to make such an emphasis too exclusively. Perhaps several of the emphases separately developed at leading colleges, could be fitted into the design of a single course. Proceeding by this hypothesis, the following components in a physical sciences sequence have been assembled for possible inclusion: (1) historical materials—not merely chronological surveys nor disregarding the social context within which science has developed—that include selected crucial controversies and the literature of science itself; (2) discussion that emphasizes precision of expression and critical thinking; (3) the rationale of scientific procedure; (4) practical (consumer) applications of science; (5) social and philosophical applications of science; (6) both demonstration and individual laboratory work; (7) introduction to literature, periodical and otherwise, directed to the layman; and (8) the sociology of science, or how it is actually supported and administered today, including a study of the proper conditions for the most effective conduct of the scientific enterprise. This is eclecticism with a vengeance! And yet it does serve to keep the advantages of these several emphases clearly in the teacher's view as he continues his design of the course.

### *Physical Sciences I*

Physical Sciences I, the first of the two years in the sequence, has come, on the basis of trying it out twice during the academic year 1947-48, to assume a fairly well-defined, however tentative, pattern. For the present, its content will be more or less established as follows. (It is hoped that the economy and power of integrating chemistry and physics will be evident even in this mere outline.)

1. Introductory unit on motion, the problem that inaugurated the modern scientific movement
  - 1.1 pre-Galilean science
  - 1.2 social and philosophical contexts for the modern solution of the problem of motion
  - 1.3 group laboratory experiment on the freely falling body
    - 1.31 graphical methods in the interpretation of data
    - 1.32 preliminary discussion of scientific procedure
    - 1.321 theory of measurement

- 1.4 "original" laboratory investigation of factors affecting the period of a pendulum
- 1.5 certain limited laws of motion
  - 1.51 Galileo's law of freely falling bodies
  - 1.52 Kepler's laws of planetary motion
- 1.6 the Newtonian synthesis
  - 1.61 first law of motion—unaccelerated motion
  - 1.62 second law of motion—constantly accelerated motion
    - 1.621 demonstration of Atwood's machine
  - 1.63 third law of motion
    - 1.631 individual laboratory work on the composition and resolution of concurrent coplanar vectors
    - 1.632 the possibility of disequilibrium, of accelerated motion in a world of action-reaction forces
- 1.64 the law of universal gravitation
  - 1.641 Cavendish "weighs" the earth
  - 1.642 exercise in deducing Galileo's law of freely falling bodies from Newton's laws of motion
- 1.65 the place of Newton in the development of Western thought
- 1.7 the accurate science of artillery
  - 1.71 vectorial representations of trajectories
- 1.8 historic controversy over "quantity of motion"— $ft = kmv \text{ vs. } fd = kmv^2$ 
  - 1.81 the emerging concept of energy
    - 1.811 potential *vs.* kinetic mechanical energy
- 1.9 absolute *vs.* relative motion—Einstein's interpretation of the Michelson-Morley data

Unit on atoms, molecules, and heat

- 2.1 the chemical composition of matter—operational distinctions, demonstrated
  - 2.11 mixture *vs.* purifiable substance
  - 2.12 compound *vs.* element
  - 2.13 physical, chemical, nuclear changes
- 2.2 the physical states of matter—operational distinctions, demonstrated
  - 2.21 solid *vs.* liquid *vs.* gas
  - 2.22 physical changes in state—laboratory work in purification techniques
  - 2.23 the reality of gases—the consequences of the "pneumatic revolution" in science
- 2.3 kinds of mixtures—operational distinctions, demonstrated
  - 2.31 coarse, colloidal dispersions, solutions
    - 2.311 "original" laboratory determination of the solubility of a salt
- 2.4 founding of chemistry as a science
  - 2.41 historical origins of chemistry
  - 2.42 three fundamental laws, inductively established
    - 2.421 Lavoisier: conservation of matter
    - 2.422 Proust: definite composition of compound
    - 2.423 Dalton: multiple combining proportions

- 2.43 Dalton's atomic theory: turning point of the controversy between atomists and continuists
  - 2.431 Dalton's procedure: necessary and sufficient assumptions
    - 2.4311 demonstration of supporting evidence, suggestive and "conclusive"
- 2.44 Lavoisier's oxidation theory replaces the phlogiston theory of burning
  - 2.441 individual laboratory preparation and study of oxygen
- 2.5 theoretical reinterpretation (in terms of atoms and molecules) of all preceding operational distinctions
- 2.6 laboratory determination of relative equivalent weights of the chemical elements
- 2.7 the nature of heat, inseparably connected with the theory of the fine structure of matter
  - 2.71 laboratory study of heat transfer down temperature gradients through different surfaces (selection of roofing materials)
  - 2.72 caloric *vs.* kinetic molecular controversy "settled" by Rumford's memorandum
  - 2.73 thermometry: the physical gas laws and the location of the "absolute zero"
    - 2.731 Perrin's work on the relationship between absolute temperature and the " $mv^2$ " of colloidal particles in Brownian movement
    - 2.732 operational and theoretical distinctions between temperature and heat
- 2.8 Avogadro's hypothesis, based upon Dalton's atomic theory, the physical gas laws, and Gay-Lussac's law of combining gaseous volumes
  - 2.81 the controversy between Avogadro and Dalton
  - 2.82 on the basis of Avogadro's hypothesis, the laboratory determination of the molar volume of oxygen
    - 2.821 pegging the relative weight of the oxygen atom at 16.0000 by definition, the laboratory procedure for determining relative molecular weights of volatile substances
    - 2.822 mathematical relationship involving three important properties of a chemical element: relative equivalent weight, relative atomic weight, combining power
    - 2.823 the highest common factor method of determining the relative atomic weight of a nonvolatile element
- 2.9 chemical notation and nomenclature—toward a reading (not writing!) knowledge of chemistry
  - 2.91 what a chemist can calculate from a properly written equation
- 3. Unit on the technical bases of the early industrial revolution
  - 3.1 the design of machinery
    - 3.11 actual *vs.* ideal mechanical advantage
      - 3.111 the concepts of work, of efficiency
      - 3.1111 the force of friction

- 3.1112 the mechanical equivalent of heat (demonstration-determination)
- 3.12 laboratory study of all simple types of machines and of compounded machines
  - 3.2 the development of the heat engine
    - 3.21 historical derivation from the cannon and the pump
      - 3.211 external *vs.* internal combustion engines
      - 3.212 reciprocating *vs.* turbine operations
      - 3.213 Watt's achievements—including
        - 3.2131 the concept of power
    - 3.22 Sadi Carnot's analysis of the ideal heat engine
      - 3.221 the two laws of thermodynamics
    - 3.23 calorimetry: procedures based on the theory of heat transfer
      - 3.231 specific *vs.* latent heat—based on demonstration determinations
        - 3.232 kinetic *vs.* potential heat energy
    - 3.24 classification of energy forms—the unique nature of kinetic heat energy
  - 3.3 review of kinetic-molecular theory of matter and heat
  - 3.4 energy resources and national policy—the issues identified by the late National Resources Planning Board
  - 3.5 combustion of fuels—providing 96 percent of the energy technically controlled in the national economy
    - 3.51 Faraday's "chemical history of a candle"
    - 3.52 the control of fire—practical demonstrations
    - 3.53 our important fuels: solid, liquid, gas- 4. Brief unit—entirely laboratory—on the types and control of chemical reactions
  - 4.1 types of chemical reactions: synthesis, analysis, simple replacement, double replacement
  - 4.2 carefully designed experiment studying in turn the factors controlling the rate of a chemical reaction
  - 4.3 Le Chatelier's principle—applied to the shifting of the equilibrium of a reversible reaction
- 5. Unit on the periodic law and atomic structure
  - 5.1 fields of force—the concept of potential
    - 5.11 magnetic fields around poles—laboratory plotting
    - 5.12 electric fields around charges—laboratory plotting
    - 5.13 gravitational fields around masses
  - 5.2 direct electric current in a conducting circuit—its chemical effects
    - 5.21 laboratory study of Faraday's laws of electrolysis
      - 5.211 hypotheses suggested thereby on nature of chemical affinity and of electricity
      - 5.212 "original" investigation of the electrode products of electrolyses
    - 5.22 the electrical equivalent of heat—the meaning of coulomb, ampere, volt, ohm, watt, watt x second

- 5.3 classification of the chemical elements
  - 5.31 laboratory distinction between metals and nonmetals based on the acidic or basic properties of their oxides and hydroxides
  - 5.32 demonstration of family resemblances and trends—using three halogens
  - 5.33 Mendelejeef's discovery of the periodic classification, relating increasing atomic weight to combining power and to "family" membership
- 5.4 the revolutionary discoveries of the 1880's and their effects both on the attitudes of physical scientists and on our knowledge of the fine structure of matter: demonstrations of
  - 5.41 cathode rays (electrons)
    - 5.411 Millikan measures the charge on the electron
  - 5.42 x-rays
    - 5.421 Moseley's revision of the periodic law
  - 5.43 radioactivity: alpha, beta, gamma rays
    - 5.431 Rutherford discovers the nucleus
    - 5.432 the onion-skin theory of atomic structure
      - 5.4321 atomic diagrams "explain" the chemical properties of the elements and the periodic classification
    - 5.433 isotopes, explained in terms of the number of neutrons in the nucleus
    - 5.434 the distinction between radioactive and chemical changes
      - 5.4341 the intriguing problem of the source of nuclear energy

### *Physical Sciences II*

Physical Sciences II, the second year of the sequence, will be offered for the first time in the fall of 1948. Building on the basis of Physical Sciences I, any of several points of departure is feasible. The following units will be available for selection: ionic processes (proton transfer, electron transfer, qualitative analytical procedure); nuclear processes; industrial physical science, built around motion pictures and field observations (winning the metals, the "heavy chemical" industries); carbon chemistry, with emphasis upon living processes; electrical energy (generation, control, use by means of appliances in the housing circuit); wave phenomena (music, electromagnetic radiant energy); the radio, illustrating electronic devices. Obviously, there is more than enough material to occupy a class for an academic year. It is, therefore, intended that both the content of Physical Sciences II and the sequence of included units will always remain largely open to decision by the stu-

dents. Physical Sciences II need not and will not be the same for one group of students as for another.

Still another list of units, of a rather different sort, has been compiled. This list has been organized according to the kind of collaboration needed if the unit is to be properly developed and taught: earth science, life science, home making, play production, photography, music, social science, and philosophy. These units will await development as the needed collaboration is achieved. Their range and diversity may be suggested by a few examples: the physical processes accounting for weather; our mineral resources; the photosynthetic process; basal metabolism; the human eye; soil as a key resource; the automobile engine; stage lighting; how science is involved in defining the good life—for instance, good housing; the flow of energy and materials through the economy of industrial Dayton; how science is involved in maintaining the good community—for instance, the public utilities; federal support of science; social control of atomic energy; scientific method and the epistemological problem.

Always the strategy is to build a rich and well-organized file of proven materials (in lieu of a text) from which the course for each assembled class or divergent individual can be flexibly reconstructed. These proven materials will include: (1) outlines of lectures, including those that collaborating teachers are willing to give; (2) demonstrations that have been found successful; (3) issues (social or philosophical) for critical thinking through by small discussion groups; (4) field observations that have proved successful; (5) laboratory investigations, some completely organized, some representing long-time projects, and some requiring the formulation of hypotheses and refinement of techniques; (6) reading references; (7) annotated compilation of audiovisual aids; (8) problem assignments and test items (many objective in type and to be statistically validated); and (9) large course units that have been found effective. In each instance, the feasible objectives will be clearly stated.

Students enrolled in either Physical Sciences I or Physical Sciences II are always invited to devise individualized projects which, under careful accounting, can be substituted for any equivalent selection of course requirements. Students unused to taking this initiative in their own education have hesitated

to cut themselves loose from the security of the syllabus. But many students have completed successful projects which made connections with either their cooperative work experiences, their fields of specialization, their hobby interests, their work in some other course, or their specific problems as consumers. It is by means of this opportunity for individualization, that the problem of the extremely diverse backgrounds of the students promises to be solved. It is intended both that a student never find himself repeating something he has "had" before, and that he assume responsibility for finding the most direct connection between physical science and his life.

#### THE LONGER FUTURE

The longer future of general education at Antioch College may be referred to in closing. It is only proper to reveal that there is considerable doubt among Antioch teachers concerning the proper designation of such a course as has been described in this article. Currently offered as one of the required courses, it might sometime come to be considered as an elective. This fate might, indeed, simultaneously overtake most of the required courses. And the required nonwaivable core of the general education component in the curriculum might conceivably become a sequence of experiences quite unprecedentedly integrating the competences of representatives of all the divisions of the faculty. One can imagine panel-guided courses of four equivalently valuable and necessary kinds: (1) a course including the orientation and other services of the college, directed to the personal-social needs of maturing adolescents; (2) a course illuminating the development of the "one world," affording a chronological perspective and avoiding superficiality by intensively concentrating upon certain specially significant cultures or transitional periods in human history; (3) a course investigating selected, crucial contemporary issues, again, to avoid superficiality, a very few such issues genuinely analyzed by *bona fide* problem-solving procedures rather than affording opportunities for teacher indoctrination of students with certain "solutions" (or with the idea that there are no solutions!), thus providing indispensable experience with using scientific procedures for problem-solving; and (4) a course (more correctly, an institute) for developing and trying out processes whereby a community can be assisted to become really a community, united in democra-

tic deliberation and action toward improving its way of life. (Antioch students have the exciting possibility of using many communities as laboratories for this purpose.)

It might well be that, in such contexts as these, the physical sciences would make their properly indelible impression, as they are discovered to be both relevant and intelligible. Perhaps through such experiences, an Antioch graduate would prove both sensitive in recognizing the relevance of the physical sciences in any particular instance and able to locate the resources by which he could learn the specific physical science he needed, in that instance, to know. A college so designing its liberal education would, of course, find a wholly new relationship with the larger community.

The over-all, integrating theme for the general education component in liberal education might come to be: *the power for good of scientific and democratic procedures, when co-ordinated in the solving of problems.* The over-all, integrating theme for the physical sciences, within the broader context, might come to be: *how the description and control of the flow of energy and materials through processes and events enables man both to understand the world and to change the world to his enduring advantage.*

## The General Course in Physical Science at Oklahoma A. and M. College

THE PROGRAM of general education at Oklahoma A. and M. had its beginning in the School of Arts and Sciences in the fall of 1935. The stimulus of fifteen years of curricular experimentation, beginning at Columbia College and at the University of Chicago then taken up by a half-dozen other institutions, is a familiar story, and one that had challenged the interest of some members of this faculty. A committee was appointed to study the curriculum in particular relation to the basic requirements for all students who were candidates for degrees in the School of Arts and Sciences. This committee recommended that the subject-matter fields be divided into four divisions—physical sciences, biological sciences, social sciences, and humanities—and that a basic survey be offered in each. All students were required to take the three survey courses outside the division of their major, and it was assumed that they would receive no further instruction in these divisions. In practice, the humanities course became an exception, for it became a required course for majors in English and music as well as majors in the other divisions.

In the course of two years divisional committees worked out plans for and the faculty initiated four basic courses.

The general course in physical science was conceived as a selection of basic materials from physics, chemistry, geology, and astronomy. Both in subject matter and organization, it is characterized rather accurately by the phrase, "a survey of the physical sciences."

The biological science course is a survey of the basic concepts and principles of the biological sciences. It differs from the usual divisional survey in the relatively greater stress it places

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on human physiology and preventive medicine. In terms of the estimates of students, the respect of the faculty, and approval of the lower-division advisers, the biological science course has been the most successful element of the program of general education up to this point.

Perhaps the greatest single contribution to the success of the program has come from the plan for advisement in the School of Arts and Sciences. The faculty advisers are released from one-fourth of their duties in order that they may devote adequate attention to this work. Upon entrance a student is assigned to one of these general advisers who helps him in planning his curriculum throughout his college career. At the end of the second year the student fills out "a study plan" which includes a record of his work up to that point and a list of the courses that he proposes to take for a major and minor and electives. The courses for the major and minor are selected by the student in consultation with departmental advisers. The general adviser at this point has before him the student's academic record and the results of the student's achievement in the upper-division general examination which gives a profile of achievement indicating areas in which the student needs further work. The success of the general education program in the School of Arts and Sciences at Oklahoma A. and M. has been due largely to the work of the advisers in the specific administration of that program in relation to the entire work of each student.

The program of general education at Oklahoma A. and M. is undergoing considerable revision at this point. A year ago it was decided to add to the staff a chairman of general education who would be responsible for guiding the revision, development, and extension of this program. In the first three areas it is not probable that radical changes in the courses will take place. Revisions that have been undertaken up to this point and those in prospect indicate that the changes will have the character of evolution from forms that have emerged over a period of time. The social science course, however, is in the process of complete replanning.

As the program has been developed up to this point and in clear prospect in the work of the committee on general education, the program of general education in the School of

Arts and Sciences at Oklahoma A. and M. can be summarized as follows: (1) the revision of the present requirement in English composition to coordinate it with an achievement test in English usage which will be a condition of admission to the upper division; (2) four general divisional courses, three of which will be required of each student; (3) a general education achievement test as a basis for admission to the upper division; (4) the use of the advisement-study plan system to guide the selection of electives in the upper division to fill out needed areas of development for each student; (5) the development of an integrative course for seniors which will probably take the form of small seminar groups.

The faculty for the courses in the program of general education now includes a greater proportion of men in senior academic ranks than other organizational divisions of the institution. This obviously expensive policy, we believe, is necessary in order to secure persons who have the breadth of training, the ability to teach, and the qualities of mind and personality necessary to continuous critical review of their own work, which is prerequisite to a progressively more effective teaching in this area. As a matter of policy, all of the members of the staff in general education are also members of the faculty in their respective departmental fields and usually teach at least one advanced course in a departmental field. We believe that this is essential to maintaining the vitality of the work of the individual instructor and contributes to the coordination of work in general education with the work of the whole institution.

The present general course in physical science at Oklahoma A. and M. is not the course that was organized and taught very successfully in the first four years of the program of general education, nor is it the course that is being replanned and will take form within the next two years. That very fact, however, may make it a particularly instructive situation to those interested in general education in this area. To that end we will outline the objectives, organization, content, and methods of the course as it is now offered, present a very frank statement of our criticisms of this course, then outline some of the plans for revision, or what might more properly be called, plans for the formulation of a new course.

### OBJECTIVES

The purposes of the course as stated in the mimeographed syllabus given to each student are: "(1) to lead to an adequate understanding on the part of the student of the major facts and principles of the physical sciences; (2) to develop the ability of the student to do critical thinking in the physical sciences; (3) to develop certain desirable changes in attitude on the part of the individual student; (4) to develop in the student a sensitiveness to the social values and implications of the sciences." At the beginning of the course these purposes are discussed in lectures and in discussions with students. It is doubtful if the second and third of these objectives operate as effective principles of control in the selection of materials and in the actual teaching in the course. As qualities, habits and attitudes are very difficult to measure, and they are much more easily stated as principles than reduced to operative techniques in teaching and learning. The first and the fourth of the stated purposes are referred to again and again in the process of teaching itself. The results of testing in the course show that the objectives are actually attained, at least to some degree.

This critical statement concerning the aims of the course, insofar as it is negatively critical, is directed fully as much at a general practice in contemporary higher education as it is to this specific course. A generation ago when each teaching situation was marked by a clearly defined body of subject matter, objectives of courses were never stated, but were commonly assumed to be the simple, single purpose of initiating the student into that traditional body of subject matter. Educational theorists began to assert that teachers should have clearly stated objectives for their teaching, and that these objectives should control the selection of materials and the methods of teaching. Without objecting to that claim, it can be pointed out that the statement of objectives in operational terms has been found to be a very difficult process indeed. The much more common practice was the statement of highly general ideals as objectives, then pursuing the business of selecting materials and teaching without much reference to these stated ideals. Some taint of this sin is found in our general physical science course.

### CONTENT AND METHOD

The course is organized on a basis of two semesters of instruction with three credit hours each. In the earlier years of the course it was offered in sections of 125 students or more. Most of the lectures were given by one instructor who invited colleagues on the staff to give occasional lectures on special topics. In more recent years it has been taught in sections of not more than 35 students each, with a single instructor for each section.

The content of the course is best described as a survey of elements of physics, chemistry, geology, and astronomy. The major emphasis has been placed on elements of physics on the ground that concepts and principles in this science have the widest application to the whole realm of the physical world. In the original planning, three criteria for the selection of the concepts and principles to be created were rather clearly stated and rigidly applied: (1) the importance of the concept or principle to science as determined by the wideness of its application; (2) the importance of the concept or principle in the nontechnical student's understanding of the nature of the physical world; (3) the value of the concept or principle as a cultural aid, that is to say, its applicability as a tool for reading and oral communication in the realm of the physical sciences.

As experience has been gained in teaching the course, it has undergone revision several times; so the criteria for the selection of topics, stated above, do not apply as clearly and directly to the present content of the course as they did to its earlier phases. Much of the revision of the course, probably too much of it, has been a process of accommodation to the quality of the preparation of the students and to the interests and judgments of a too rapidly changing staff.

#### Outline of the Course

##### Introduction

1. Purposes and methods of science
2. Purposes of the physical science survey course
3. Units of measurement

##### I. Why study science?

##### II. The material world

1. What is matter?
2. What are the physical states of matter?

3. What kinds of change does matter undergo?
4. What is the nature of molecular motion?

### III. Elementary mechanics

1. How and when do bodies move?
2. Meaning of force, energy, work, power
3. Elementary machines

### IV. Heat energy and its uses

1. What is heat?
2. How is heat measured?
3. What is the effect of heat upon bodies?
4. What is the effect of heat upon liquids?
5. What is the effect of heat upon gases?
6. What is specific heat?
7. In what general ways is heat transferred?
8. What methods may be used to lessen heat transfer?
9. What are the principles of construction and circulation in an ice box?
10. What principles of heat removal are used in ice-manufacturing plants?
11. What principles of construction and circulation are used in refrigerators?
12. What is meant by "air-conditioning?"
13. In what ways are homes heated?

### V. Magnetic properties of matter

1. Discovery of magnetic properties of materials
2. The earth as a magnet
3. Uses of magnetism
4. Molecular theory of magnetism

### VI. Electrical properties of matter

1. Production and detection of electrical charges
2. Static electricity in everyday life
3. Lightning and lightning rods

### VII. Current electricity

1. How is electricity put in motion?
2. Kinds and methods of connecting cells
3. Units and laws in current electricity
4. Uses of electrical energy in heating and lighting

### VIII. Electromagnetic effects

1. What are general effects of an electrical current?
2. Dynamos and motors
3. Spark coils and transformers
4. The evacuated tube and radio

### IX. Sound

1. What are the characteristics of vibrating bodies?
2. What are the characteristics of sound waves?
3. How is sound detected?
4. What are the auditory effects of the physical properties of sound?

5. What are overtones, harmonies, octaves, resonance, sympathetic vibrations, beats?
6. In what ways may sound effects be reduced?
7. What measures can be used for improving the acoustics of rooms?
8. Musical instruments
9. Detecting and recording sound

#### X. Light

1. What is light?
2. How has the velocity of light been determined?
3. Propagation of light
4. Reflection of light
5. Refraction of light
6. How are different kinds of mirrors used?
7. How are different kinds of lenses used?

#### XI. Color

1. What are the characteristics of color?
2. Colors of transparent and opaque objects
3. How are colors named?
4. In what ways is modern life affected by color?
5. What use is made of color in photography and advertising?

#### XII. The composition and structure of matter

- A. Into what three classes does the chemist classify matter?
  1. What is the simplest class of matter?
  2. What are compounds?
  3. What are mixtures?
- B. What is the difference between molecules and atoms?
  1. Which is the larger?
  2. What is the least and greatest number of atoms molecules may have?
- C. What is the structure of atoms?
  1. What significant events led up to the modern concept of atomic structure?
    - a. What occurs when electrical discharges are made through gases?
      - (1) What are cathode rays?
      - (2) How do cathode rays travel?
        - (a) Proofs?
      - (3) How do we know cathode rays are particles?
      - (4) What are positive rays, canal rays?
      - (5) What did Wilson's cloud chamber and Millikan's oil-drop experiment show?
    - (6) How are x-rays produced?
  2. What are the building stones of atoms?
    - a. What is an electron?
    - b. What is a proton?
    - c. What is a neutron?

3. What is the structure of a typical atom?
  - a. What is the structure of the nucleus of an atom?
  - b. What is its charge?
  - c. How are the shell electrons arranged?
    - (1) How do they compare in number to the protons in the nucleus?
  - d. Indicate the structure of several simpler elements
- D. What is meant by atomic weight?
  1. Why was an atom of oxygen taken as a standard?
- E. What is meant by atomic number?
  1. Whose work laid the basis for this concept?
  2. What is the relation between atomic number and the number of planetary electrons?
  3. What relation exists between the atomic number and the number of protons in the nucleus?
  4. Knowing the atomic weight and the atomic number, how can the number of neutrons be determined?
- F. What is the significance of the shell or planetary electrons as they affect the activity of the atom?
  1. Elements that lose electrons readily from the outer shell are called what?
  2. Elements that add electrons readily to the outer shell are called what?
  3. Elements that may lose or gain outer shell electrons are called what?
  4. What is the relation to valence of this loss or gain of outer shell electrons?
    - a. What is valence?
  5. Why are there no compounds of helium?
  6. Why do atoms form compounds?
  7. What is the difference between metals and nonmetals?
- G. What is the periodic table?
  1. How were the elements originally arranged in this table?
  2. How are they arranged now?
  3. What relations do the elements in horizontal rows have? ("periods")
  4. What relations do the elements in columns have?
  5. What uses does the periodic table have?

### XIII. Tools of chemistry

- A. How does the chemist designate an atom?
  1. What kind of symbols were first used?
  2. Who proposed our present system?
  3. What does a symbol represent?
- B. How does the chemist designate a molecule?
  1. How many elements may be present in a molecule?
  2. What is meant by molecular weight?
  3. How does the chemist write formulas?
    - a. What relation exists between valence and formula writing?
    - b. What is a radical?

- C. How does the chemist name formulas?
- D. How can the percentage composition of a compound be determined from the chemical formula?
  - 1. State the law of definite composition
- E. What does a chemical equation always represent?
  - 1. How does a chemist balance equations?
- F. How does the chemist use equations to determine amounts of material necessary and the amounts of products obtained?
  - 1. Weight reactions
  - 2. Volume reactions
- G. What is a gram-molecular volume?
  - 1. Of what use is it?
  - 2. If the formula of a gas is known, how may the weight of a liter be determined?

XIV. The earth as an astronomical body

- 1. The earth as an astronomical body
  - a. Shape and circumference observed by:
    - (1) Disappearance of ships over the horizon
    - (2) Variation of the altitude of the North Star at two different stations on the earth's station
  - b. Computation of the diameter and surface area
  - c. Rotation—daylight and darkness, Foucault pendulum
  - d. Revolution about the sun—observations on fixed stars—definition of "period of revolution"
  - e. Mass determined by:
    - (1) Measurement of the acceleration of gravity, and use of Newton's second law of motion give absolute measurement of the force of attraction
    - (2) Cavendish experiment. (Paul R. Heyl) is used to determine the "constant" of Newton's law of gravitation
- 2. Sun
  - a. Distance from earth and diameter. How is each determined?
  - b. Mass—by application of Newton's law of gravitation
  - c. Composition—use of spectroscope
  - d. Luminosity and solar constant
  - e. Surface and interior temperatures
  - f. Sun spots: discoverer, theory, and information to be gained from study of sun spots; 11-year cycle
  - g. Prominences—description, how observed
- 3. Sources of solar energy
  - a. Criterion for acceptance of theories
    - (1) Rate of emission
    - (2) Time scale—the rate of emission must have been maintained for at least two million years. (Qualified?)
  - b. Helmholtz contraction theory
  - c. Jeans — radioactivity
  - d. Millikan—formation of elements of greater atomic weight from elements of smaller atomic weight
  - e. Bethe—carbon, hydrogen, nitrogen change

4. Interior of the sun.
  - a. Significance of the photosphere, reversing layer, chromosphere, corona
  - b. Fraunhofer lines
5. Relative motion of sun and earth
  - a. Rotation of earth—use in the measurement of time
  - b. Revolution of the earth about the sun—orbit and fixed direction of the earth's axis in space. Cause of seasons on the earth
  - c. The ecliptic—the apparent path of the sun in the sky
  - d. The celestial equator
  - e. The autumnal and vernal equinoxes—the intersections of the celestial equator and the ecliptic—use to astronomers
6. The earth sphere—circles of longitude and latitude
7. The celestial sphere
  - a. Horizon system—horizon and zenith
  - b. Equatorial system—celestial equator and North (pole) Star
8. Relation of longitude to time
  - a. Importance of Greenwich, England
  - b. International date line
9. Sidereal time
  - a. Definition and method of measurement
  - b. Sidereal day (definition of vernal equinox)
  - c. Division of sidereal day
  - d. Inconvenience
10. True solar time.
  - a. Definition and method of measurement
  - b. True solar day
  - c. Cause of variation of true solar day
  - d. Differences between true solar day and sidereal day
11. Mean solar time
  - a. Definition—length of days, relation to true solar day
  - b. Relation to sidereal time
  - c. Determination of longitude. Relation between mean solar time at Greenwich and mean solar time elsewhere
12. Standard times
  - a. Relation to mean solar time
  - b. International date line—necessity and use
13. Calendar
  - a. Duration
  - b. Rule of leap years
  - c. Necessity for change from *Julian* to *Gregorian* Calendar

#### XV. Our solar system

1. General shape and size
  - a. Shape of orbits
  - b. Inclination of orbits to plane of ecliptic

2. The planets—in order of their:
  - a. Distances from sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto (The asteroids or planetoids are between Mars and Jupiter.)
  - b. Sizes—diameters  
Mercury, Mars, Pluto, Venus, Earth, Uranus, Saturn, Neptune, Jupiter
3. Motion of planets—Kepler's laws—(observational)  
1-120)
  - a. Each planet so moves that an imaginary line drawn from it to the sun (the radius vector) sweeps over equal areas in equal intervals of time
  - b. Each planet moves around the sun in an ellipse, with the sun at one end of the foci
  - c. The squares of the times that the planets require to make complete revolutions about the sun are in proportion to the cubes of their distances (major axes) from the sun
4. Newton's law of universal gravitation

Every particle of matter within the universe attracts every other particle in the universe with a force proportional to the product of the masses and inversely proportional to the square of the distance between them.

The motion of the planets as described by Kepler's laws can be shown to be a result of Newton's law of gravitation. The inward attraction of gravitation is in equilibrium with the outward centrifugal force caused by the motion of the planet in a curved path.
5. Numerical application of Newton's laws
6. Physical characteristics of each
  - a. Periods of revolution, periods of rotation, atmospheres, temperatures. Particular peculiarities.
  - b. Methods used to determine characteristics
7. The planets:
  - a. Those visible to the naked eye.
  - b. Those discovered in modern times (discoverers)
  - c. Reasoning followed by Adams and Leverrier in their prediction of the location of Neptune. Lowell's prediction of the existence of Pluto
8. The satellites of the planets
  - a. Phobos—innermost satellite of Mars has a period of revolution less than the period of rotation for Mars. Importance of this fact in theories of the formation of the solar system
  - b. Retrograde motion of the outer satellites of Jupiter and Saturn
9. The earth's satellite—our own moon
  - a. Periods of rotation and revolution, mass, size, distance from earth
  - b. Physical characteristics: atmosphere, temperature, lack of moisture, and land forms

- c. The moon as a falling body
- d. The value of 'g' on the moon
- 10. Causes of phases of the moon—the lunar month
- 11. Theories of the formation of the solar system
  - a. Laplace—the nebular hypothesis
  - b. Chamberlain and Moulton—the planetesimal theory
  - c. Objections to and evidences for each theory
- 12. Theory for the formation of the moon
- 13. Eclipses, transits, occultations; phenomena, causes of each

#### XVI. Asteroids, comets, and meteors

- 1. Asteroids or planetoids; location, orbits
- 2. Characteristics of comets: names of parts, frequency, orbits, physical makeup. Why are comets visible for only short intervals of time?
- 3. Path of Halley's comet
- 4. Why does the tail of the comet always point away from the sun?
- 5. Meteors: origin, composition, paths. Showers and shooting stars
- 6. Distinction between comets, meteors, and meteorites

#### XVII. Stars, nebulae and stellar systems

- 1. Nature of stars: size, temperature, constitution, luminosity
- 2. Distances from the earth; methods of determining each
- 3. Stellar classification
  - a. Significance of magnitudes
  - b. Significance of spectral type
  - c. Multiple types
- 4. Our own galaxy
  - a. Order, size, general shape, distribution of stars
  - b. Location of our solar system in our galaxy
  - c. Direction of motion of our solar system. Methods used in these studies
- 5. Nebulae—*intra* and *extra*—galactic
  - a. Characteristics
  - b. Determination of speeds by Doppler effect
- 6. Theories of dark spots in nebulae
  - a. Herschel
  - b. Present theories
  - c. Possible relationship to glacial periods

This brief outline of the course is expanded in detail in a syllabus. The topics are treated in relation to assigned readings in four texts: White, *Classical and Modern Physics*, Bretz, *Earth Sciences*, Fisher and Lockwood, *Astronomy*, and Ahrens, Bush, and Easley, *Living Chemistry*. The lecture-discussion method is used in each of the sections of the course. Since the number of students is from 20 to 35, the class sessions are usually conducted in a rather informal manner. The effectiveness of this method has varied greatly with individual in-

structors. Usually the sections are scheduled so that two of them may be paired into a single section on the third meeting of the week for a demonstration-lecture. Careful work has been done on these demonstrations, and they have, on the whole, been very effective. Motion pictures, slides, and the projection of opaque material are used as well, but it is the common judgment of the staff that their own demonstrations are more effective.

Through most of the history of the course the tests have been uniform for all sections. They have been of the "objective" type: multiple choice, matching, and completion. In the notes of one instructor on the tests, there are the statements: "It has been many years since any student has had a perfect score on a test paper. It is our belief that the test items often require much more than a memorization of the textual material or the demonstrations. Ability to diagram, to interpret data, to reason and to do critical thinking are often involved."

#### CRITICISMS

It must be said that on the whole the operation of the general physical science course in the last two years has been very unsatisfactory. Studies and evaluations of the course have been made by members of the staff in the physical science departments, by advisers, and by the chairman of general education. These studies have been based on observation of the teaching, examination of the tests, the reports of students, and interviews with the staff. Doubtless, many of the criticisms stem from the fact that it was reinstated at the end of the recent war with a temporary staff and with a temporary chairman. The difficulties now experienced can be summed up under four heads.

The first and most important is staff. The chairman of the committee which planned the original course and who gave the principal lectures during the first five years was a physicist doing capable research in his own field as well as being a very excellent teacher. He had a clear understanding of the purposes of general education and a deep conviction of the significance of this work. These qualities made him a very effective leader of his colleagues. Early in the war he, and most of the others who had worked effectively in the course, went into research connected with the war effort and they have re-

mained in these laboratories. As a result the course was discontinued from the spring of 1942 until the fall of 1946. In the past two years it has been taught by men on temporary assignment.

Our experience with staff in this course is instructive in relation to the current discussion of training of teachers for general education courses. Many of those discussing this topic have recommended the distribution of graduate work in several of the traditional departments of science instruction. It has been our experience that men so trained do not make good teachers. On the other hand, the most successful teachers in courses of this kind are men who have done outstanding work in graduate study and research in a particular field. The qualities of breadth of cultural interest and understanding of educational processes seem to have come from that unidentifiable sum of experiences and associations that make the person of cultural breadth, human sensitivity, and creative imagination, causing him to approach situations with a freshness and vitality of insight and interest. Our experiences led us to the conviction that the primary qualification for effective teaching in this area is the type of person, rather than a particular pattern of training. Indicative in this connection is the fact of a quite varied experience in trying out the use of graduate fellows in the course. A few of them have done the most effective teaching that we have had, while most have had all the weaknesses usually attributed to graduate fellows as instructors.

A second difficulty with the course, as presently taught, is in testing. The college has not had an examiner whose services could be used in test construction. As noted above, the type of test has been wholly "objective." Constructed by men who are inexpert in test formulation, the questions are often poorly stated, ambiguous, or fail to state the conditions essential to an unequivocal answer. The other difficulties are inherent in the type of test used. On the assumption that tests, more than any other single factor, set the actual objectives of a course, the exclusive use of the objective test falsifies the attempt to teach an understanding of science or the commonly stated objective, "understanding the scientific method." Tests of this type actually teach the student the method of authority.

A third ground for criticism of the present course is the attitude of most of the instructors, and the students as well. Unlike any of the other general divisional courses, it is regarded as a less worthy, less respectable, easier way out for "the nonscience major." It is not uncommon for an instructor in teaching a particular topic to point out to the students that "it is impossible to treat the topic adequately except in mathematical terms, but this course is a nonmathematical course. Consequently, the treatment must be superficial, and any understanding of the topic can be partial at best." The progressive accommodation to what is called "beginning where the students are" has led to very unsatisfactory grading and instructional standards. It is not uncommon for better than average students to report the judgment that they "got a great deal out of the course," but wish that they had been required to work harder, or that they did not deserve the grades that they received.

The fourth criticism of the course will be met in nearly all institutions which have attempted work in general education over a period of several years. It springs from the fact that the first attempts in this area were, almost without exception, the formulation of a general divisional course as a "survey course." In spite of the fact that planning groups vigorously asserted that they would not create a course simply by putting together elements of traditional, introductory, departmental courses, they, nevertheless, tended to think in terms of "a survey of the physical sciences," rather than a basic course in physical science. Reference to the brief outline of the content of the course above, clearly reveals the fact that ours is such a survey course. It is constructed as a sequence of materials from departmental fields. Both instructors and students speak of the "physics section," the "chemistry section," the "geology section," and the "astronomy section."

#### PLANS FOR REVISION

Professor Malcolm Correll is the recently appointed chairman of the course. He is a physicist with several years experience in teaching the general physical science course and the natural science course in the College of the University of Chicago. In his discussions with the chairman of general education and the committee on general education, a few well-

defined elements in a plan for the revision of the course appear. It is expected, however, that at least two years will be required to reduce these ideas to specific elements of a plan in operation.

During the replanning interim, the material and the plan of the course will be set very largely by the use of a single text, the work of Krauskopf of Stanford University. This decision was made on the judgment that it is one of the best planned texts available, and that the use of this single text will permit the correction of some of the conditions that have existed in the course, until the work of replanning can be accomplished.

The second conviction that will guide our replanning is that we need more clearly defined objectives that will control the selection of materials and teaching methods, thus providing a basis for the integration of the work. Adequate statement of these objectives comes, of course, only as the result of a considerable period of work in the process of replanning itself. In advance of that work, they can be stated only tentatively. Among objectives readily current in our present discussions are: (1) to make the student literate in the field of the physical sciences (we mean by this giving the student an acquaintance with the vocabulary, the forms of statement, the principal topics, the modes of dealing with them that will enable him to read serious but nontechnical literature); (2) to lead the student to understand the work of scientists (attempt to replace the naive attitude which attributes infallibility to whatever is called "science" or "scientific," by understanding and appreciation of the methods and procedures that define the problems, seek their solutions, and arrive at conditional answers); (3) to provide a basis, at least, for the understanding of the relations of science to the whole complex of cultural development.

We believe that these three objectives can be reduced to operational principles in the selection of material and in the processes of teaching. Even a brief examination of them indicates that much of the material in the traditional survey course may be left out without limiting the accomplishment of these objectives. On the other hand, they would require the introduction of more historical material and the treatment of that material in such a way that the student understands

it in its own context rather than the usual rapid story of "the errors of the past" as contrasted to the "truth" of the present.

Our discussions thus far indicate that the materials of the new course will be a weaving together of three different types. In addition to much of the material that is common to the contemporary text—that is to say, material which introduces, explains, and illustrates concepts—there will be a limited use of the outstanding documents in the history of science, and some use of the "problems approach." Without being convinced that the best method of teaching a general course in physical science is the exclusive use of the documents that record the successive stages of growth of these sciences, we are, nevertheless, committed to the notion that some of the values that can be achieved in understanding the enterprise of science through the firsthand record of the crucial studies and discoveries should be included in the education of the student. Likewise the work of the group at Colgate University, in the last five years, on the development of a course in physical science centered in seven problems has demonstrated the value of this method. We believe that it is possible to achieve some of the values of their approach to the work by using it as one element in a course rather than as a method of organizing the whole course.

## Science Survey Courses in Secondary Schools

**A**t THE turn of the century the secondary school population was represented by a rather highly selected group of pupils. The past forty or fifty years, however, have been marked by an increase in enrollment that has brought quite a different situation into being; for example, twenty-eight states reported in 1940 that 90 percent of all 14- and 15-year-old children were in school.<sup>1</sup> The retention of pupils through high school graduation now approximates 50 percent for the nation as a whole, and in some educationally favored states the figure is much higher. Thus, even the senior high schools have become less and less selective, and today they are, to all intents and purposes, part and parcel of the common school.

One very important concomitant of this change in pupil personnel was the rise of individual difference as a major problem of instruction, carrying with it implications for changes in courses of study. Another perplexity also became inescapable as time went on. Fifty years ago only a small percentage of pupils who graduated from high schools went to college; today the situation differs only in degree, and there is little question that many potentially competent students never enroll in colleges. In fact, the colleges would be incapable of accommodating all individuals who might successfully attend. High school training is therefore terminal training for a considerable proportion of the population.

To be sure, reports of current policy-making committees and commissions quite generally call for a greatly broadened base of collegiate education in the United States. For example, the President's Commission on Higher Education has recently

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<sup>1</sup>The highest percentage reported by any state was 97.

recommended an extensive program of federal aid for American colleges and universities, looking forward to an ultimate doubling of student enrollment.<sup>2</sup> Even though this recommendation were adopted and implemented in whole, however, high school training would continue to be the last contact with organized instruction for a large group of individuals. This being the case, it may be asserted with some authority that the program of elementary and secondary school science instruction must be such as to make well-rounded and substantial contribution to the aim of general education.

It now becomes desirable to attempt some clarification of what we mean by "general education." A substantial contribution to our modern interpretation of this term was made in *A Program for Teaching Science*, including the rather specific summary statement: "This committee . . . recognizes the responsibility for selection of subject matter which shall be functional for guidance toward a more satisfactory adjustment of the individual to the society of which he must be a part."<sup>3</sup> Not long thereafter, *Science in General Education*<sup>4</sup> directed attention to teaching science intimately related to what were defined as five broad areas of life experiences. A third and somewhat similar interpretation of the objectives of science teaching was contained in *Science Teaching for Better Living*.<sup>5</sup> The Educational Policies Commission Report<sup>6</sup> outlined recommendations for the general education of youth, and recognized the importance of training for personal growth, social usefulness, citizenship, stimulation of intellectual curiosity, ability to think rationally, and appreciation of ethical values. This report has been criticized as one which does not place sufficient emphasis upon the importance of science education, but whether such criticism is justified or not the document represents a landmark in development of the general education concept. Together

<sup>2</sup>The President's Commission on Higher Education, *Higher Education for American Democracy* (Washington: U. S. Government Printing Office, 1947).

<sup>3</sup>National Society for the Study of Education, *Thirty-First Yearbook, Part I: A Program for Teaching Science* (Bloomington, Ill.: Public School Publishing Co., 1932), p. 40.

<sup>4</sup>Progressive Education Association, *Science in General Education* (New York: D. Appleton-Century Co., 1938).

<sup>5</sup>American Council of Science Teachers, National Committee on Science Teaching, *Science Teaching for Better Living* (Washington: National Education Associations, 1942).

<sup>6</sup>Educational Policies Commission, *Education for All American Youth* (Washington: National Education Association, 1944).

with the more recent Harvard Report,<sup>7</sup> it makes the point that science instruction in elementary and secondary schools should be implemented by general courses. All of the foregoing reports, although not necessarily in agreement with respect to individual policies, appear to have recognized, either directly or by implication, the importance of a kind of education in science which will enable the individual to make more intelligent responses to the situations and problems that confront him in the experiences of everyday life. Taken as a group, these reports have fostered an emphasis on general education, and this must be reckoned with in any present-day evaluation of science education.

While the emphasis upon general education was in the making, World War II intervened, and by its very nature brought recommendations that turned the front of educational reforms in a somewhat different direction. With widespread recognition of the major role played by the mechanisms of science and by scientists in the late conflict, with commonplace reference to the "push-button" wars that have been prophesied for the future, and with surviving nations squabbling over possession of inventions, near-inventions, and captured technicians, it is perhaps inevitable that a certain amount of concern should be expressed over the apparent fact that during the war years a disproportionate number of potential scientists failed to receive training, and that, in any event, increased postwar demand for scientific workers probably would have created a shortage. Thus in *Manpower for Research* it is stated that ". . . war curtailment of education, plus its after effects, deprived the nation of about half its normal increase in scientists—35,000, including some 5,000 doctors of science. The shortage of scientists is the product of a sharply increased demand, accompanied by a less-than-normal supply."<sup>8</sup> The scientific workers referred to, of course, are not the products of secondary schools alone; however, secondary schools clearly are involved in their earlier training. The really significant decision that must be made, insofar as the topic under discussion is concerned, is the decision as to when specialization in scientific

<sup>7</sup>Harvard Committee, *General Education in a Free Society* (Cambridge: Harvard University Press, 1945).

<sup>8</sup>J. R. Steelman, *Manpower for Research*, Vol. 4 of *Science and Public Policy* (Washington: U. S. Government Printing Office, 1947), p. 3.

training should begin in the case of those individuals who possess the requisite capacities and interests.

At first thought, it might be concluded that the recommendations of general education and the need for scientific manpower are rather hopelessly opposed, yet in practice such is not necessarily the case. Actually, many leaders of scientific thought and action assert that the successful specialist must have a broad understanding of modern culture, including the interrelationships of the various sciences, upon which to rear the superstructure of his specialty, and it is insisted that progress in science will be advanced as the general public gains in understanding of science and its potentialities. So we return again to the key question as to when specialization should begin, and its corollary which concerns whether or not this should be at the same maturity level in the case of all individuals who can hope to carry on advanced studies with profit. These questions are real and imposing, and the authors may not hope to answer them with finality, but may perhaps presume to suggest ways and means of dealing with them in part.

### THE RISE OF SURVEY COURSES IN SECONDARY SCHOOLS

Survey courses, or "broad-field" courses in secondary school science are not a new thing. It would not be unreasonable, for example, to take the position that general biology was the first of these courses to appear upon the high school science scene. At the turn of the century, the old parent courses in high school botany, zoology, and physiology were faltering. In 1905 the University of the State of New York issued a syllabus in general biology. Textbooks reflecting the recommendations of this syllabus were published and widely adopted. This first "general biology" was little more than three short courses—botany, zoology, and physiology bound under one cover. It marked a turning point, however, and in time was supplanted by the "fused" courses or "blended" courses, in which it was more or less axiomatic that subject-matter "boundaries" of botany, zoology, and physiology should be ignored.

The present-day course in general biology, commonly offered as a tenth-grade elective, is the product of the latter trend. Its materials are drawn from the sciences of botany, zoology, and physiology to be sure, but in addition from anthropology, psychology, and historical geology, with the result that the

offering has become relatively broad in scope, and especially so in view of the added fact that there is increasing tendency to interpret life phenomena in terms of chemistry and physics.

In addition, considerable thought and effort have been devoted to the project of selecting life science materials that have validity for the curriculum because they have direct bearing upon questions, issues, and problems involved in the interests and needs of young people; for example, the source books of Sears,<sup>9</sup> Glass<sup>10</sup> and Fitzpatrick,<sup>11</sup> and an analysis of biological principles from the standpoint of their importance to general education carried out by Martin.<sup>12</sup> At the same time, studies by Bingham<sup>13</sup> and Urban<sup>14</sup> (high school pupils) and by Bond<sup>15</sup> (college students) have given rather definite indication that what might be called the general education emphasis is, or at least may be, truly functional.

It is well recognized that general biology (high school) has largely supplanted the older courses in botany, zoology, and physiology. Thus, at the time of the relatively recent Carnegie survey, Miller found that ". . . zoology, botany, and physiology are now taught relatively infrequently."<sup>16</sup> In fact, no high school text in any of these subjects has been published for many years. Meanwhile, the general biology course has risen to a place of prominence in the secondary school. It is almost universally offered on an elective basis, but data indicate that somewhat more than half of the pupils who enter high school will take the course.

<sup>9</sup>P. B. Sears, *Life and Environment* (New York: Bureau of Publications, Teachers College, Columbia University, 1939).

<sup>10</sup>H. B. Glass, *Genes and the Man* (New York: Bureau of Publications, Teachers College, Columbia University, 1943).

<sup>11</sup>F. L. Fitzpatrick, *The Control of Organisms* (New York: Bureau of Publications, Teachers College, Columbia University, 1940).

<sup>12</sup>W. E. Martin, "A Determination of the Principles of the Biological Sciences of Importance for General Education," *Science Education*, XXIX (March 1945), 100-105, and (April-May 1945), 152-63.

<sup>13</sup>N. E. Bingham, *Teaching Nutrition in Biology Classes* (New York: Bureau of Publications, Teachers College, Columbia University, 1939).

<sup>14</sup>John Urban, *Behavior Changes Resulting from a Study of Communicable Diseases* (New York: Bureau of Publications, Teachers College, Columbia University, 1943).

<sup>15</sup>A. D. Bond, *An Experiment in the Teaching of Genetics* (New York: Bureau of Publications, Teachers College, Columbit University, 1940).

<sup>16</sup>D. F. Miller, "General Information on the Experience and the Subjects Taught by Biology Teachers" in Oscar Riddle, et al, *The Teaching of Biology in Secondary Schools of the United States* (Columbus, Ohio: Committee on the Teaching of Biology of the Union of American Biological Societies, 1942), p. 10.

While the aforementioned transition was being effected on the biological front, other changes in the science offering of the secondary school were in progress. The period after 1910 was marked, for instance, by the rapid rise of general science courses, especially in the grades of the junior high school. They were supported by strong recommendations from a policy commission of the National Education Association.<sup>17</sup> In a sense, these general science courses, like the general biology courses, were of the survey or broad-field type. By 1920 they had gained widespread acceptance, and they were incorporated as part of a continuous program of science instruction in recommendations of *A Program for Teaching Science*, from which the following statement is selected: "The committee advocates for grades seven, eight, and nine a three-year integrated program of science study, organized not on the basis of any special science or sciences, but rather upon the basis of large topics, problems, or units relating to the significant problems that arise out of present-day experiences."<sup>18</sup>

There is evidence that the general science trend has followed the recommended pattern rather closely during the past twenty years. For instance, it is indicated in *Science Education in American Schools* that ". . . the science courses of the junior high school have become relatively stabilized. The content is in effect a spreading and an enlargement of general science to cover the science needs of pupils of this maturity level."<sup>19</sup> Thus, a second generalized science offering has come into being in the American secondary school, sometimes on a required and otherwise on an elective basis.

There is every present indication that the general science and general biology courses will persist in grades seven to ten inclusive, although in some school systems which adopt core curricula, their identity as "courses" may tend to be lost. Insofar as grades eleven and twelve are concerned, however, the apparent destiny of science instruction is far less evident.

<sup>17</sup>National Education Association, Commission on the Reorganization of Secondary Education, *Reorganization of Science in Secondary Schools*, Bureau of Education Bulletin No. 26, 1920.

<sup>18</sup>National Society for the Study of Education, *Thirty-First Yearbook, Part 1: A Program for Teaching Science* (Bloomington, Ill., Public School Publishing Co., 1932) p. 194.

<sup>19</sup>National Society for the Study of Education, *Forty-Sixth Yearbook, Part 1: Science Education in American Schools* (Chicago: University of Chicago Press, 1947), p. 138.

These upper grades of the senior high school have been the "stronghold" of chemistry and physics for many years, but they have been a stronghold in name only, for courses in chemistry and physics have fared none too well from the standpoint of pupil enrollment, even though they have been more or less supported and subsidized by college entrance requirements. The trend in pupil enrollment between 1910 and 1928, as reported in *A Program for Teaching Science*,<sup>20</sup> showed that physics had dropped from 14.6 percent to 6.9 percent, and that chemistry had varied from 6.89 percent to 7.10 percent. It also was noted that the once-popular physical geography had dropped from a pupil enrollment of 19 percent in 1910 to 3 percent in 1928. In fact, United States Office of Education data<sup>21</sup> indicate that although the percentage of pupils taking courses in general science and general biology increased after 1910 and remained fairly stable during the thirties, the percentage of enrollments in the more specialized courses, especially physics, waned during this same interval, and has become stabilized at a lower level in more recent years. Similar testimony from a study conducted by Hunter<sup>22</sup> indicated that about twice as many pupils were taking biology in the tenth grade as were taking chemistry and physics in the eleventh and twelfth grades.

Perhaps the failure of secondary school courses in chemistry and physics to attract a larger enrollment, the changing nature of the school population, new conceptions of general education and its purposes, and the relative success of general science and general biology all combined to focus attention upon the possibility, if not the necessity, of developing broad-field physical science courses in the senior high school. At any rate, an imposing number of "experimental" offerings appeared during the thirties, were suppressed somewhat by the exigencies of World War II, but have flowered forth anew in the postwar period.

The origin and development of physical science and similar courses in the senior high school has been, to some extent,

<sup>20</sup>*Op. cit.*, p. 244.

<sup>21</sup>United States Office of Education, *Offerings and Registrations in High-School Subjects, 1933-34*. Bulletin No. 6 (Washington: U. S. Government Printing Office, 1938).

<sup>22</sup>G. W. Hunter, "The Sequence of Science in the Junior and Senior High School," *Science Education*, XVI (December 1931), 103-15.

paralleled by and associated with the rise of the general education emphasis. This relationship is documented, for instance, by the studies of Wray<sup>23</sup> and Gillson,<sup>24</sup> both of whom were dealing with chemistry course content in an effort to identify materials of greatest functional value. At about the same time Schlesinger<sup>25</sup> published a paper on the contributions of laboratory work to general education, and Vordenburg<sup>26</sup> analyzed possible contributions to general education by high school physics. The authors cited, of course, were not all thinking in terms of potential survey or physical science courses; as a matter of fact, there has been an attempt to revise the high school chemistry and physics courses so as to make them more acceptable from the general education point of view. Similarly, the development of broad-area physical science courses has been related to various studies in the area of consumer education, such as the investigation of Partridge<sup>27</sup> and Harap, which concentrated upon the identification and classification of scientific terms having significance in the science education of consumers, and the more recent recommendations set forth in the consumer education study.<sup>28</sup>

Other investigations having to do with the general education potentialities of physical science courses were conducted by Wise,<sup>29</sup> who evaluated a large number of physical science principles in terms of their potential usefulness, and a study by Peterson<sup>30</sup> in which materials drawn from the subject areas of chemistry and physics were organized in the form of instruc-

<sup>23</sup>R. P. Wray, *The Relative Importance of Items of Chemical Information for General Education*, Pennsylvania State College Studies in Education, No. 6 (State College, Pa., 1933).

<sup>24</sup>Margery S. Gillson, *Developing a High-School Chemistry Course Adapted to the Differential Needs of Boys and Girls*, Contribution to Education No 709 (New York Bureau of Publication, Teachers College, Columbia University, 1937).

<sup>25</sup>H. I. Schlesinger, "The Contribution of Laboratory Work to General Education," *Journal of Chemical Education*, XII (November 1933), 524-28.

<sup>26</sup>K. E. Vordenberg, "High-School Physics for General Education," *School Science and Mathematics*, XLI (June 1941), 548-52.

<sup>27</sup>W. A. Partridge and Henry Harap, "Science for the Consumer," *School Science and Mathematics*, XXIII (March 1933), 266-74.

<sup>28</sup>National Science Teachers Association, statement prepared for the *Consumer Education Study* (Washington: National Association of Secondary-School Principals, 1945).

<sup>29</sup>H. L. Wise, "A Determination of the Relative Importance of Principles of Physical Science for General Education," *Science Education*, XXV (December 1941), 371-79, and XXVI (January 1942), 8-12. Also, "A Synthesis of the Results of Twelve Curricular Studies in the Fields of Science Education," *Science Education*, XXVII (February 1943), 36-40, and (September-October 1943), 67-76.

<sup>30</sup>S. W. Peterson, "The Evaluation of a One-Year Course, the Fusion of Physics and Chemistry, with Other Physical-Science Courses," *Science Education*, XXIX (December 1945), 255-67.

tional units. On a slightly different front, Brown,<sup>31</sup> Bailey,<sup>32</sup> and Carleton<sup>33</sup> developed courses which had their roots in classroom experimentation, and undoubtedly tended to give impetus to the rise of high school physical science courses in the country as a whole.

#### THE PRESENT STATUS OF SCIENCE SURVEY COURSES IN SECONDARY SCHOOLS

With the foregoing facts concerning the philosophic and historical backgrounds of secondary school science survey courses in mind, it may be profitable to consider their present status in the schools of the nation. It must at once be apparent that impetus for the development of such courses has had its roots in the profound changes that have occurred in secondary school populations, and the correspondingly altered point of view taken by educators in general. This altered point of view has influenced the thinking of science educators in turn, and they have given attention to the possibilities of (*a*) modifying existing science courses, and (*b*) creating new offerings which are more in line with the modern trend.

A recent survey<sup>34</sup> carried out by Hunter and Ahrens carries the implication that classroom teachers of science may be somewhat behind the educational procession when it comes to recognition of immediate and practical utility as criteria for selecting learning experiences. None the less, if we accept general science and general biology as being courses of the survey type, we are faced with the pertinent fact that they have become rather well established, that they give every indication of being perpetuated, and that sincere efforts are being made to improve them in terms of the general education aim. Or, as suggested in *Science Education in American Schools*, ". . . the general trend in science courses throughout the junior high school, senior high school, and junior college has been toward

<sup>31</sup>H. E. Brown, *The Development of a Course in the Physical Sciences for the Lincoln School* (New York: Bureau of Publications, Teachers College, Columbia University, 1939).

<sup>32</sup>W. W. Bailey, "Physical Science for the Eleventh Year," *Science Teacher*, IX December 1942), Yearbook Supplement, No. 17.

<sup>33</sup>R. H. Carleton, "Physical Science for General Education," *Science Counselor*, VII (1941), 7 (March), 48 (June), and 81 (September).

<sup>34</sup>G. W. Hunter, and H. J. Ahrens, "The Present Status of Science Objectives in the Secondary Schools of California," *Science Education*, XXXI (December 1947), 287-95.

generalized courses planned to meet the more immediate science needs of the common users of science.<sup>35</sup>

That physical science in the high school has not prospered also may be in part attributed to the fact that college entrance requirements and various comprehensive examinations have had the effect of perpetuating the *status quo*, and of "freezing" the content of chemistry and physics courses. There is some evidence that this state of affairs is in process of change, as set forth in Carlton's<sup>36</sup> recent analysis of the acceptability of physical science as a college entrance unit. Widespread acceptance of the physical science course in such capacity would, of course, remove the principal barrier to more general representation in the high schools.

As matters stand, no physical science course has to date gained the general approval that has been accorded to general science and general biology. As indicated in *Science Education in American Schools*, there is ". . . considerable difference of opinion as to what subject-matter content is appropriate."<sup>37</sup> Some courses incline toward the consumer emphasis, and others tend to concentrate upon science principles and their applications. Some courses derive their materials almost wholly from the areas of chemistry and physics, whereas others incorporate materials from geology, meteorology, and astronomy as well. Some have been developed as two-year sequences, and others are confined to a single year. Immediately prior to World War II these somewhat diverse courses were on the increase, and they were identified by such titles as physical science, science, consumer education, consumer science, science survey, fused physical science, and senior science.

Hunter and Spore reported that some 7,000 California pupils were registered in physical science courses in 1938-39.<sup>38</sup> Shortly thereafter Watson<sup>39</sup> determined that physical science had become a common offering in the larger cities of twenty-six states. There can be little doubt but that this offering fell off some-

<sup>35</sup>National Society for the Study of Education, *Forty-Sixth Yearbook, Part I: Science Education in American Schools* (Chicago: University of Chicago Press, 1947), p. 139.

<sup>36</sup>R. H. Carlton, "The Acceptability of Physical Science as a College Entrance Unit," *Science Education*, XXX (April 1946), 127-32.

<sup>37</sup>*Op. cit.*, p. 192.

<sup>38</sup>G. W. Hunter, and Leroy Spore, "Science Sequence and Enrollments in the Secondary Schools of the United States," *Science Education*, XXVI (February 1942), 66.

<sup>39</sup>D. R. Watson, "A Comparison of the Growth of Survey Courses in Physical Sciences in High Schools and Colleges," *Science Education*, XXIV (January 1940), 14-20.

what in competition with the preinduction courses of the war period; however, there is evidence to indicate that physical science courses are now on the increase. Quoting *Science Education in American Schools* again, prediction of a general increase in the physical science offering may be based upon ". . . recognition of the superior possibilities of a composite physical science over the separate traditional chemistry and physics courses in contributing to the aims of general education, and . . . the disposition of colleges to recognize the physical science course as a bona-fide college-entrance unit for the non-science major."<sup>10</sup>

There is, therefore, every reason to believe that the high school physical science course has come to stay, as a part of a sequence which begins with elementary science, and extends through general science and general biology. Doubtless the future will see more general agreement as to what the content and emphasis of this relatively new course should be; in fact, its very existence opens new and inviting avenues for research in science education.

#### RELATIONSHIP OF HIGH SCHOOL SCIENCE SURVEY COURSES TO COLLEGE SCIENCE COURSES

Had the high school science teachers and curriculum makers not turned their attention voluntarily to the development of broad-field courses, such action would have been forced upon them by events transpiring at the college level. Johnson<sup>11</sup> traces the early development of college survey courses in the social studies and the natural sciences, indicating that they had their origins about 1918, and that they became increasingly popular during the twenties and thirties as the general education aim gained widespread acceptance in collegiate circles.

As might be expected, a good many different kinds of survey courses were developed by the experimenters, both in the secondary schools and in colleges. All of them, however, may be assigned to one of two general categories insofar as the science teaching program is concerned. The first general type is represented by the survey of science, in which, as Johnson states ". . . the areas of the general field are presented in a

<sup>10</sup>*Op. cit.*, p. 191.

<sup>11</sup>B. L. Johnson, *What About Survey Courses* (New York): Henry Holt and Co., Inc., 1937), Chap. 1.

series like the cards in a catalogue."<sup>42</sup> Many of the pioneering survey courses were of this nature, and they took their departure from the organized presentations of materials in existing textbooks. The second general type of survey course was not defined by pre-existing textbook content or the outlines of the special subjects. Rather, the approach to selection of materials was environmental, and was concerned with an analysis of problems encountered in the immediate community or the world community, and with the needs of students insofar as the latter could be identified. Clearly, the second type of course was better adapted to implementation of the general education aim. Johnson<sup>43</sup> attempts a further classification of these courses as (1) comprehensive courses, (2) selective courses, (3) analytical courses, and (4) descriptive courses.

By 1935, the college survey courses in science had made considerable headway. Havighurst<sup>44</sup> analyzed the science survey offerings of 64 liberal arts colleges in 1935-36, and found that they were generally of three types: natural sciences, physical sciences, and biological sciences. Most of them were of rather encyclopedic natures and, not unlike secondary school courses, they usually were presented through the media of lectures, demonstrations, and discussions. A common practice was to have several specialists participate in the presentation of such a course. Winokur<sup>45</sup> made another analysis of college science survey courses at about the same time, and found that such offerings were represented in universities, colleges, teachers colleges, junior colleges, and normal schools in all parts of the country. Winokur's data were obtained from 98 institutions, of which 47 offered a single generalized course in natural science, and 20 offered separate courses in physical science and biological science; the remainder paired a new general course such as physical science with some established biological offering. It was estimated that about 80,000 students were taking generalized science courses in 1936. A further analysis of science survey courses offered by 23 liberal arts colleges and

<sup>42</sup>Ibid., p. 37.

<sup>43</sup>Ibid., pp. 204-206.

<sup>44</sup>R. J. Havighurst, "Survey Courses in the Natural Sciences," *The American Physics Teacher*, III (September 1935), 97-101.

<sup>45</sup>Morris Winokur, "A Survey of Generalized Science Courses in Institutions of Higher Education," *Science Education*, XX (October 1936), 132-40.

33 teachers colleges, made by Pruitt,<sup>46</sup> revealed some additional facts, and particularly that such courses rarely incorporated individual laboratory work.

Watson's<sup>47</sup> analysis of college catalogue statements (1937-39), which included 86.1 percent of 1,239 liberal arts colleges, teachers colleges, normal schools, junior colleges, and negro colleges, showed that 387 institutions offered physical science survey courses of one sort or another. His data indicated that the survey of natural science course apparently was becoming less popular, and was being superseded by a survey of physical science, or a "semisurvey" of physical science.

The foregoing studies clearly document the conclusion that the rise of physical science survey courses in the senior high school has been paralleled by a similar development at the junior college level. Also, practices have not been consistent as to scope and emphasis (as one might expect in the case of experimental courses), and the general result has been not a little confusing. It does not seem wholly consistent, for example, that some pupils should take special field courses such as physics and chemistry in the high school, and then be registered in science survey courses after they have entered colleges; this seemingly paradoxical development has, of course, been forestalled by the counseling programs of some institutions. Moreover, the nation's need of scientific manpower remains an unpleasant reality, and carries with it the urgent demand that specialization be not delayed *ad infinitum*.

At the moment, the science survey courses of the senior high school and the junior college clearly are not very well articulated, and there has been no generally accepted criterion for this relationship; in fact, when one considers the aforementioned diversity of existing courses it is hard to see how there could be. On the other hand, the criterion for establishing sequence in the study of a special subject is clear. In his study of chemistry, for example, the student begins with a general course, the content of which is largely determined by standard textbooks. Such content includes terminology, descriptions of processes, and principles judged by the author to be basic, and if the book has widespread use the implication is that many

<sup>46</sup>C. M. Pruitt, "Survey Courses in the Natural Sciences," *Science Education*, XXI (February 1937), 10-16.

<sup>47</sup>D. R. Watson, *op. cit.*, pp. 14-15.

chemistry teachers are in essential agreement with the author's judgments. More specialized studies follow the general course, in which the student progresses toward the graduate school and a research career. The functions which the courses are designed to serve are presumed to determine the sequence. The survey courses which have been introduced into secondary schools and colleges, however, are not designed to serve the same ends as the older specialized courses; therefore, an attempt to apply the criterion for sequence in specialized courses to determination of sequence in survey courses probably would result in confusion.

### FUTURE DEVELOPMENT AND POLICIES

As previously suggested, the immediate function of survey courses is to help young people gain the competence which they want and need at the time when they are engaged in study. For example, young children will play with their toys, and this act is for them a learning experience with phenomena outside themselves. On more mature levels they are challenged by increasingly complex questions about the physical universe and about life. The sequence of learning experiences from one maturity level to another is in general toward the achievement of successful adulthood as this is defined in a democratic society. This achievement includes qualities of personality which make the individual acceptable in his society, and competence to comprehend and to work for the development of cultural ideals and attitudes. Students of growth and development are revealing more and more about the changes that occur in young people as they mature. It seems obvious at this time that the most useful criteria for sequence in science survey courses will be derived on the one hand from the many careful studies of mental and physical growth and, on the other, from analysis of social and cultural needs.

Some of the impetus for development of broad-field science courses in the senior high school has had its origin in concern for the slow learner. This approach is neither sound nor defensible. Rather, the concern is that all pupils be brought in contact with those scientific facts, attitudes, and understandings which have widespread applications in the affairs of their everyday life. Consummation of such a purpose necessarily implements the basic aim of general education.

To assume that full realization of this aim would automatically solve all learning problems of the common school, however, is naive. Individual difference is an inescapable biological fact, and no matter how closely a science teaching program approached the ideal, some pupils would profit more than others. Sectioning of classes upon the basis of pupil ability would doubtless remain a problem of greater or lesser proportions even though instructional materials were demonstrably ideal. We could, however, be reasonably sure of one thing: that what pupils did learn would represent materials from a selected fund of knowledge that is deemed to be desirable in the common educational heritage.

It is a well-known fact that a sequential science program has been in process of development in elementary and secondary schools for some little time, and that during the past twenty years it has come to take rather definite form. The trend seems to be in the direction of generalized study, as recommended in *General Education in a Free Society*, wherein the statement is made that ". . . below the college level virtually all science teaching should be devoted to general education."<sup>48</sup> It may be suggested, perhaps, that the greatest progress toward such a goal has been made in elementary science, general science, and general biology, but that considerable work by way of refining programs remains to be accomplished. Teachers of senior high school chemistry and physics, laboring under the artificial but real inhibitions of rather sharply standardized courses of study and college entrance requirements, have tended to remain unchanged in outlook. It has become increasingly apparent that there is a real place for the right type of physical science course in the senior high school. It is also obvious that a more definite relationship between secondary school and college survey courses must be established.

As previously noted, the development of survey type courses has been concomitant to an increasing emphasis on general education. One design of survey courses has been to give broader experience with the subject matter of the cultural heritage; that is, to give an experience with science rather than with special science. Another purpose has been to equip young people to deal intelligently with the actual problems of living. Learn-

<sup>48</sup>Harvard Committee, *op. cit.*, p. 158.

ing experiences for the first purpose may be and frequently are determined by relations among phenomena as these phenomena are represented in the environment. For the second purpose, immediately personal and environmental phenomena set the problems which are in turn the criteria for the selection of learning experiences. Courses designed for either purpose will in fact have much in common, and will be in contrast with special subject offerings.

Working out of the background of concern for more adequate science teaching to serve the needs of today's youth, Powers and groups of college and high school teachers have instigated innovations in several schools and prepared reports. Some of these innovations have been described in periodical literature. A full description of this cooperative work has now been prepared and will appear in a forthcoming volume.<sup>49</sup>

As educators with major interest in sciences gain increasing familiarity with studies of growth and development, and familiarity with conclusions drawn from these studies, we may expect general abandonment of requirements that young people should devote time during their formative years to the study of topics which have remote values that will never be realized by the average individual, even though he "passes" the subjects involved. Instead, learning experiences more appropriate for normal growth and development, and having more obvious relationship to the immediate business of living, will constitute the general education curriculum. Survey courses in science represent a transition between the specialized courses designed and standardized to provide narrow training for a highly selected population, and an offering in general education appropriate for aiding all youth to play an acceptable part as citizens and workers in national and world affairs.

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<sup>49</sup>Anita D. Laton and Samuel Ralph Powers, *New Directions in Science Teaching*, A Report of a Cooperative Project in Seventeen Schools carried on by the Teachers College, Columbia University, Bureau of Educational Research in Science (New York: McGraw-Hill Book Co., in press).

## Trends in Science Courses in General Education

THIRTY YEARS ago colleges tried to assure some breadth of learning among their graduates by requiring that students elect at least one course in each of the areas outside their major field of interest. Under this plan those chiefly interested in the study of the humanities or the social sciences were required to pursue one course in the natural sciences. Since elementary instruction in physics, chemistry, geology, zoology, and botany was designed primarily for those who intended to take advanced work, it necessarily dealt intensively with the detailed subject matter basic to further instruction. And since these introductory courses treated only one subject with little relation to the other sciences, students even under the most favorable circumstances left such courses with considerable knowledge of a single subject but little of any other. Moreover, they gained only a limited understanding of science as an intellectual method or of its impact on modern life.

Shocked by the narrow and specialized knowledge which college graduates possessed, the faculties of several institutions shortly after World War I set about a reorganization of the curriculum with the purpose of increasing the breadth of students' knowledge and the diversity of their intellectual skills. In the field of science their efforts to broaden instruction for students who did not expect to spend their lives in scholarly activities produced the survey course. Such courses, which became popular in the late twenties and thirties, included material from physics, chemistry, geology, astronomy, and mathematics in the physical sciences, and a similar range of subjects in the biological sciences. Since the academic calendar provided little more time for the survey of all the physical sciences than was hitherto given to a conventional course in one, those

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By Earl J. McGrath, dean of the College of Liberal Arts, State University of Iowa.

who constructed survey courses had the choice of retaining a large part of the several separate courses of which the survey was composed and covering that more hurriedly, or selecting a few representative topics from the constituent subjects and dealing with these intensively. Unfortunately most institutions chose the former of these alternatives.

These early efforts to remodel courses in science for non-science students were not successful. After a few years they were basically altered in some institutions, in others completely abandoned. The principal reason for their failure was their unavoidable superficiality. They attempted to cover so much ground that students resorted to habits of memorizing a vast array of facts. The better students acquired a certain glibness in talking about science, to be sure, but they gained little real comprehension of its laws or the methods used in their derivation. The danger in this type of instruction was the students' belief that they knew something about science and scientific method, when often they had actually only learned a mass of miscellaneous facts.

Educators began to realize that even superior students could not in the time available cover any significant portion of the subject matter of three, four, or more sciences. The laudable ideal of trying to acquaint ordinary undergraduate students, many of whom possessed no special scientific aptitude, with the ever-growing body of scientific fact could not be realized. But a more important factor in the disappearance of the survey course was the realization that it was unnecessary to cover so large a body of material to reach the principal goals of instruction in science. A re-examination of the principles of learning revealed that, contrary to an earlier view, transfer of training was possible, that the mind had the capacity to generalize its experience at a highly abstract level when the learning situation was designed to achieve this objective. Hence it was not only possible but desirable to shift the emphasis in science instruction from the learning of detailed facts to the understanding of laws or principles of general applicability.

Dissatisfied with the first attempts to provide better courses in science for the nonmajor student, but unwilling to return to the practice of having the student elect an introductory course in one of the sciences, enterprising teachers began to

experiment with another type of course. Though there is considerable variation from institution to institution in the purposes, content, and organization of these courses, certain common features are apparent. They are like neither survey nor elementary courses. They do not cover a large body of material in all the various sciences, nor encompass all the details of one. These new courses for the nonspecialist treat intensively a few selected topics, laws, or problems in several sciences without supplying all the connecting tissue of detailed fact included in the earlier survey courses. In the physical sciences, for example, a course of this type customarily includes material from physics, chemistry, and geology, and sometimes astronomy and mathematics. Since such courses, however, usually consist of only two or three lecture-demonstrations, a discussion section, and commonly, though not always, several hours of laboratory, the necessity for a discriminating selection of topics from the constituent sciences is obvious, if superficiality is to be avoided on the one hand and fractionation on the other. Makers of general science courses have tried to steer between the Scylla of shallowness and the Charybdis of fragmentation by treating a few topics intensively to assure thoroughness, while at the same time tying the topics together with the connecting thread of scientific method, or some other binding principle. To stress the co-operative character of the scientific enterprise and the unity of scientific thought, problems are selected to which several of the sciences have contributed.

This theory of general education finds concrete expression at Northwestern University where the subject matter of seven sciences is organized around representative problems. In describing something of the philosophy of the course and illustrating one of its segments Professor O. J. Overbeck says:

Various plans for the course were suggested and discussed at length. There was early agreement that it must not be a short survey of the several sciences, but that it must emphasize the unitary nature of science and its mode of development. A selection of the basic laws of nature was made, laws which the educated man should not only know but understand. This understanding in nearly all cases required the assimilation of materials from all the classical branches of science . . . .

The laws of nature are treated as a unit rather than departmental areas. For example, the lecture on energy involves several sciences:

Astronomy—the dynamic characteristics of all bodies of the universe;

the radiant energy of the sun as our principal energy source.

Botany—the restoration of our energy supply through photosynthesis.

Chemistry—release of heat energy by chemical changes.

Geography—effect of earth topography on the availability of several forms of energy.

Geology—the accumulation of available energy in geological deposits.

Physics—the laws of thermodynamics, energy transfer, and conservation.

Zoology—animals as heat engines.

Such intensive treatment of a few topics necessarily reduces the scope of the material considered, but this is not a serious limitation, for the purpose is not to supply the student with all the available information in a particular science, but rather through the study of a few important topics or crucial experiments to acquaint him with the methods employed in gaining scientific knowledge. This emphasis on methodology highlights the principal difference between earlier and present general courses—the former emphasized the product of science, the latter its methods and its impact on modern life.

Efforts to integrate the subject matter of several sciences to reveal its unity have raised questions concerning the number of sciences that can profitably be included in a general course and how they should be organized. Practices vary from a single-science course in which one instructor, using one subject as a point of departure, reaches out when occasion requires for related material in other sciences to a course in which seven or eight specialists in as many sciences contribute their knowledge to the illumination of particular topics. The advantages of the single-science course are vigorously defended by Professor Taylor of Oberlin College and Professor Alyea of Princeton, both of whom offer such instruction. Professor Alyea believes that the single-science more completely achieves the objectives of instruction in science than the broader course. The student's curiosity is more keenly aroused, he learns more of the facts of science, and he becomes more efficient in the exercise of critical judgment. Professor Taylor feels that the world is now in a critical situation in which it is of the most urgent importance that our people learn quickly the meaning of science and its significance in modern life. But there are few teachers who are capable of teaching the subject matter of several sciences, and it will be many years before any significant number can be trained. For purely practical reasons, therefore, Professor Taylor thinks

that the single-science course is the solution to the problem or organizing appropriate instruction for the layman.

Nevertheless, there seems to be a growing conviction among science teachers that the subject matter of general courses should be more comprehensive than that included in one subject. Because of the paucity of instructors qualified to teach broad courses of this type, however, and because of the lack of instructional materials, it may be that in the immediate future practical considerations will limit the scope of such courses. In any event the best that can be hoped for at present in most institutions is a course embodying either the physical or the biological sciences, but not both. The majority of institutions which have a program of general education have so divided the field.

Where separate courses exist in the biological and in the physical sciences there has been much discussion as to whether all students should be required to take both. It is argued by some that to live intelligently in this complex world students must gain a knowledge of the two broad fields of science. Thus far, however, a number of institutions have not prescribed both on the ground that the chief objectives of instruction in science should be to cultivate an appreciation of scientific method and its uses, and to show the impact of science on modern life. Since both of these purposes can be realized through the study of either a biological or a physical science, the dual requirement is not considered necessary. Other faculties (and an increasing number) require at least a semester's work in each field in order that students may gain a knowledge of the basic laws and principles in the several sciences as well as an understanding of scientific method and the place of science in the modern world.

In imposing these broad requirements in science as well as in other fields, faculties recognize that students may be duplicating educative experiences they have had in high school or in the informal activities of life. Hence, examinations are being used to an increasing extent to relieve students of requirements when they can demonstrate that they already possess the prescribed knowledge and skills. This practice will alleviate a serious problem in general courses caused by the miscellaneous background of students especially in publicly controlled institutions which admit all graduates of the sec-

ondary school without regard to the character of their previous education.

Since at present almost none of the general courses require prerequisite study, some students have had little or no science and mathematics while others have had four or five courses. There are a few exceptions, Wesleyan University, for example, where students are admitted to the general science course only after they have had one laboratory science, learned something of the philosophy of Plato, Aristotle, and Descartes, and had some college mathematics. And at Northwestern University the course is based upon one quarter of college mathematics. But these are distinct exceptions, and since the practice of permitting students to elect the majority of their courses in both high school and college will undoubtedly continue, no common preparation can be assumed in most institutions. Moreover, even those who have had courses in science exhibit the widest variation of knowledge and understanding. It would seem unreasonable, therefore, for the present at least, to lay down prerequisites for admission to general courses either in science or in the other disciplines. The administration of admissions tests in the various subject-matter areas, based upon the objectives which the required courses are supposed to cultivate, should provide a more reliable basis for judging whether or not students possess the requisite knowledge and skills.

The organization and content of general courses in science cannot, however, be determined until their purposes or objectives have been decided. Though many institutions have a list of eight or ten such objectives they can be classified under a relatively few major heads, the most common of which is the cultivation of an appreciation of the scientific method and the ability to use it. There is growing agreement that students may learn some of the facts of science without acquiring an understanding of, or the ability to use, the intellectual methods which have been successful in penetrating the secrets of the natural world. Students may "learn" Boyle's law, for example, and repeat the experiments upon which it is based without gaining any real understanding of controlled methods of scientific thinking and experimentation. The student fails to generalize the methodology of science. Hence he does not realize that this method which has produced such spectacu-

lar results in the natural sciences can also be used to advantage in the investigation of contemporary social and economic problems, and in meeting the minor emergencies with which the lives of all men are beset from time to time. If students are to learn how to use scientific method and acquire the habit of doing so, they must receive explicit instruction to this end. Hence, the newer courses in science for the non-specialist student uniformly emphasize this objective and select materials and teaching methods calculated to make possible its achievement.

Many general courses in science have the related, but wider, objective of cultivating a philosophic, analytical, critical habit of mind toward all aspects of life and reality. At Colgate University, for example, an effort is made to jolt the student out of the habit of accepting authoritarian statements regarding any matter. Similarly, at Western Washington College of Education problems from everyday life are analyzed, broken down into their constituent elements, and attacked with the use of critical judgment and scientific procedures. In its most comprehensive form this objective covers the development of a whole philosophy of life or at least a philosophic way of looking at things. There are several strong advocates of the view that general courses in sciences are inadequate unless they raise fundamental problems of cosmology, the nature and destiny of man, and the relation between science and religion. One of the strongest of these is Professor Edwin C. Kemble of Harvard University who says of his own teaching:

One minor aspect of the course remains to be mentioned. This is the contact made in the course with the problem of the relation of science and religion. A discussion of this problem in a conventional introductory course in a special science might seem out of place, but in a course that purports to exhibit the relation between science and philosophy the question should not be wholly avoided—at least that is my view. Actually the collateral reading in Randall's *Making of the Modern Mind* thrusts upon the students a consideration of this aspect of the impact of science upon our culture. The issue is of great importance to them and to modern society.

Though this is not a widely held point of view, recent courses for students who do not intend to become professional scientists reflect a greater interest in the philosophic implications of the subject.

Another common objective has to do with the facts of science. When current statements of aims refer to the student's

becoming acquainted with facts in the various sciences, only a representative selection of leading principles and laws is contemplated. Those who teach classes in science for non-major students do not minimize the value of factual material. On the contrary, they try to demonstrate the superior reliability of knowledge produced by the use of scientific methods over that produced by less exact procedures. But in planning courses of this type the basic question is: "How many and what kind of facts should the course encompass?" For example, let it be supposed that the student is expected to gain an understanding of the theory of evolution. To achieve this result examples of all the various phylla in the biological world might be examined, in considerable detail, as is often done in elementary courses in zoology and botany. But the same results can be achieved through the intensive examination of a more limited range of materials. Speaking of the desirability of selecting only a few topics to illustrate scientific principles, President Conant, one of the staunchest advocates of this procedure, says:

The question arises, therefore, whether a rigorous and detailed study of a few simple situations would not be more instructive than the necessarily superficial treatment of modern discoveries and applications which constitute a considerable portion of our present courses in freshman physics and chemistry.

The second assumption is closely related to the first one. It assumes that for the nonscientist the value to be obtained from a science course at the college level should be an appreciation of the procedures by which the different branches of science have been advanced in modern times. The acquisition of a vast mass of information is to be considered of no significance. Introduction to a certain number of basic concepts is, of course, essential but these concepts may well be limited in number.

At Colgate, where this philosophy has had its most rigorous classroom application, the result is a course organized around seven significant problems in the physical and six in the biological sciences. In commenting upon this modest selection of topics Dean French says:

The acquisition of a complete sequence of facts or principles is of far less importance in general education than the understanding of how certain facts or principles contribute to the solution of a problem. In natural science this concept leads away from a survey, necessarily superficial, of the highlights of modern achievement to a more careful study of a few problems, in an endeavor to understand what factors contributed to the solution—and how, and why.

Insofar as facts are emphasized they deal with procedural

rather than substantive matters. The objective is to give the student sufficient understanding of a few generalizations of science and the methods scientists employed in deriving them in the hope that in later life he will be able to use not only the facts themselves but also the method.

The third most common objective is concerned with the impact of science on modern life. Conventional instruction in science has given scant consideration to the relation of the work of the scientist to the social order of which it is such an important feature. In fact, scientists, like their fellow men in other walks of life, have only recently become conscious of the fact that ours is a science-centered culture, a civilization in which a technology based on science has shaped our lives and our thinking often in subtle and unobserved ways. It is increasingly apparent that unless the proper social controls can be exercised the latest work of scientists may nullify all the benefits to human kind that have flowed from the activities of their fellow workers in earlier days. Hence courses for those who will not be scientists or physicians or engineers, but who nevertheless in a democracy determine social policy which may wreck modern culture, or destroy the scientific enterprise itself, must, a growing number of scientists are agreed, instruct students in the social implications and consequences of scientific work.

A few institutions, but an increasing number, have as a fourth objective acquainting the student with the historical development of science to reveal how the cooperative efforts of succeeding generations of scientists have been responsible for our present knowledge and to indicate the evolution of scientific thought. Professor J. W. Abrams of Wesleyan University, who teaches a course in which the history of science is the unifying principle and the predominant feature, has offered the most cogent reasons for organizing general courses for nonscience students on a historical basis. He says:

The historical method has been chosen for several reasons. First, science is more readily shown to be a developing and growing process rather than a mass of uninterpreted factual material and unconnected methods. Second, the interrelationships of science with other fields of knowledge are easily illustrated when one considers the origin of scientific concepts. Third, new concepts in science can be more readily assimilated when they are viewed alongside the particular problem responsible for their postulation or development. Fourth, simpler and more concrete ideas can be used to lead

up to the modern complex and more abstract ones. Finally, the history of science is considered to have considerable intrinsic value in its own right as another aspect of the history of civilization.

Colgate, Louisville, Pennsylvania College for Women, the University of Chicago, Antioch, and other institutions, utilize considerable historical material, without making this the dominant theme of the courses.

Considering colleges as a whole, however, it can be said that the history and philosophy of science do not constitute prominent elements in these general courses. The outcome of the present innovations at Harvard and Wesleyan will no doubt determine whether more or less historical and philosophical material will be included in the future. More experience than that of these two institutions will be needed to determine whether such courses suit the needs of ordinary underclassmen, because both the Harvard and Wesleyan courses have been open only to juniors and seniors, and at Wesleyan only those who have had a laboratory science, some philosophy, and college mathematics are admitted. Whether such instruction is too advanced for ordinary college freshmen and sophomores is a question which yet remains to be answered. In any event the fact that in the coming year (1948-49) freshmen will be admitted to Mr. Conant's course, originally open only to upperclassmen, is evidence that a general science course organized on a historical basis is considered within the intellectual capacity of Harvard freshmen with little or no scientific, historical, and philosophic background.

These are the four principal objectives of instruction in science for the student who does not intend to go on in a scientific career. Others include training in the application of scientific knowledge to the everyday problems of life, mastery of the techniques of scientific investigation in the laboratory, and the development of the creative powers of the individual. The meaning of these other objectives is self-evident, with perhaps the exception of the latter of which Professor George W. Stewart of the University of Iowa is the leading proponent. Professor Stewart believes that the first purpose of instruction in science for all types of students should be the development of their powers for independent and creative thought. Though he recognizes that human beings differ in their capacity for such types of intellectual

activity, he believes that all human beings are capable of more creative intellectual work than they usually achieve. Therefore he argues that one of the principal purposes of teaching, especially in science, is to cultivate these important human capacities. In his own words,

"It is high time that the cultivation of the habitual attitude of creativeness be stressed in general education, and that students be made aware of their possession of the requisite general abilities, effective in any effort of thinking and doing."

In the use made of the various teaching methods general courses in science exhibit great variation. Lectures, discussions, demonstrations, and laboratory work are all used, though lectures, the most common form of teaching in the earlier survey courses, are less widely used today. Though there is by no means unanimous agreement, those with the longest experience believe that courses consisting of a series of lectures by specialists are not as satisfactory as those in which one instructor handles the class throughout the year, either in lecture groups or discussion sections. Nevertheless the former are quite common and no doubt will continue to be in the future because most chemists, physicists, geologists, and astronomers are either unable or unwilling to teach even the elementary aspects of a subject other than their specialty. The education of college teachers is so narrow that few have the breadth of knowledge needed in teaching a course which includes more than one science, and the attitudes cultivated in the graduate schools militate against their studying more widely in later life. For these reasons courses in science for the nonmajor student in many institutions must be a series of lectures by specialists.

Some integration of the various sciences may be achieved, however, through the attendance of the entire staff at all lectures. By hearing the presentations of his colleagues each lecturer can relate his own subject matter to theirs, and to a set of controlling ideas. Thus wasteful duplication and the omission of topics of essential importance are avoided, and the essential unity of science can be exhibited in a way that would be otherwise impossible. Three institutions—the University of Iowa in *The Biology of Man*, Northwestern University in *An Introduction to Science*, and Haverford College in *A General Course in Physical Science*—have employed this proce-

dure with the result that the subject matter and the methods of several sciences have been unified in a systematic treatment of a number of major topics. The attendance of the entire staff at all the lectures, combined with weekly group meetings to discuss such problems as the presentation of material, the use of teaching aids, and the joint construction of examinations, have resulted in an integration of subject matter which can be excelled only when all lectures and class discussions are the responsibility of a single person.

Those institutions, however, which have had the longest experience with general courses, Chicago and Colgate, for example, use the lecture method very sparingly. There most of the teaching is done in small discussion sections of twenty-five or thirty students, conducted throughout the course by one instructor who handles all the material from the several sciences involved. In describing the advantages of this type of teaching over the lecture system Professor Henshaw says:

Colgate's experience with survey courses demonstrated the wisdom of having one instructor handle a section throughout the entire term, rather than having a series of specialists. Hence, this practice is being continued. The handicap of the instructor's limited background is more than compensated for by the continuity of approach and by the many threads of unity which he can weave through the various materials studied during the term. He also is able to know his students in a way he never could if he saw them for only a few weeks. The successful class meeting is neither a lecture nor a recitation of the traditional type. It consists rather, of an active exchange of ideas, the instructor assisting in clarifying concepts and encouraging students to judge explanations by the degree to which they fit observable facts.

The training of an instructor for such a course is no small problem. Even though we were fortunate in having a nucleus of those with experience in the former surveys who had obtained some familiarity with fields other than their own, the selection of a few topics for intensive study in several fields of science caused these experienced teachers to feel quite unprepared. This problem was and is being met by scheduling weekly staff meetings or seminars when over a cup of coffee instructors compare notes on teaching devices and successful approaches to specific teaching problems. They also discuss material to be used in subsequent class sessions, with the member in whose field the topic falls in charge. These staff meetings have been one of the most stimulating phases of the course as far as the instructors are concerned.

One of the unanswered questions about science for students who do not expect to pursue a scientific career concerns the amount and kind of laboratory work they should have. Though

there are some stout defenders of the idea that such instruction can be dispensed with in general education, the majority are of a contrary opinion. Even among the latter, however, there are many who believe that conventional laboratory exercises for the future specialist are unsatisfactory because of their excessive emphasis on techniques of investigation and routine procedures. For students who will not need these skills in further study many favor laboratory which involves more demonstration by the instructor, more discussion of experimental findings by the class itself, a smaller number of more broadly selected experiments than is common in elementary courses, less individual reporting of the results, and a greater use of the laboratory time in demonstrating scientific method rather than in repeating uninspiring laboratory routines. The adaptations made in the usual laboratory procedure to fit it to the needs of nonmajor students is well illustrated by the practices at Haverford College which Professor Cadbury describes as follows:

Laboratory work is an integral part of the course. During the first semester we performed ten experiments, and each student spent one evening at the observatory. We have gone on the principle that we would do experiments if they furthered the main purpose of the course—increasing the student's understanding of science. When no suitable experiment occurred to us, we omitted laboratory work and devoted the time of the laboratory period to discussion, oral quizzing, and working of problems under supervision of, and with the help of, the instructor. These few discussion periods may not have been adequate; it would probably be better to do still less laboratory work and devote more time to discussions. Problems were assigned almost every week, and the more difficult ones were discussed at the beginning of the laboratory periods. The development of laboratory techniques is not one of our objectives.

Many institutions have reduced the amount of laboratory work of the conventional type and substituted in its place demonstrations by the staff. Usually these demonstrations parallel the lectures, but a few institutions are setting aside a period of several hours one day a week to be used to reproduce the sequence of experimental steps that originally lead to the formulation of an important scientific law or principle. At Colgate, for example, where instruction in science is conducted in small groups of twenty-five students, all sections convene in a large amphitheatre for several hours on one afternoon a week when members of the staff recapitulate the development of a scientific law by lecture, by discussion, and

by a complete redoing of the original experimentation. These class sessions and the accompanying demonstrations are so elaborately and carefully prepared, and conducted with such skill, that the observer actually feels a participant in the search for new knowledge. At the same time the lecture, or running commentary, as it should more properly be called, focuses the student's attention on the most important aspect of the entire procedure, the methods which the scientist used to get an answer to his hypothetical question concerning the behavior of nature. Through a review, and sometimes an actual demonstration, of the abortive attempts scientists made to get such an answer students learn that science is a halting process of discovery, in which the investigator makes wrong guesses, enters blind alleys, and spends much time that the uninitiated might consider wasted. This type of elaborate demonstration may very well be a suitable substitute for the individual laboratory work which is for some institutions prohibitively expensive, and considered by some of questionable value for the nonscience student.

Nevertheless, most scientists still feel that the handling of laboratory apparatus, the direct observation of an experiment in progress, and the sense of satisfaction that comes from the solving of an "unknown" are experiences which should be had even by students who do not intend to become scientists. Hence it may be expected that laboratory work of some type will in the immediate future continue to be an element in general courses in science.

Some institutions have also found that visual aids, though not an adequate substitute for the work of the laboratory, do assist in making experiences concrete which otherwise must remain mere verbalization. The use of teaching aids often makes possible the presentation of areas of science that would otherwise be completely inaccessible to students. In geography, for example, moving pictures can transport an entire class to far removed regions of the earth and by the use of still pictures geological formations of a particular region can be analyzed almost as completely as if the student were on the spot. Likewise in the biological sciences such things as the development of an organism can be pictured which because of the time involved, to say nothing of the practical problems of arranging class sessions for the purpose, would

ordinarily not be feasible. The almost universal testimony of those who have seriously tried teaching aids is that they are invaluable in bringing the world into the classroom and in making concrete scientific concepts which otherwise would remain mere word pictures of reality. Those who must use the lecture exclusively will benefit especially from the use of these devices.

The inauguration of general courses in science has created a difficult curriculum problem by disturbing the relationships between first courses in science and advanced instruction. This maladjustment is particularly troublesome in institutions which do not prescribe general courses for all students, for where the student is free to take a general or a specialized course to satisfy the science requirement some enter elementary courses in physics or chemistry, for example, without any previous science instruction whatever, while others enter after having completed a general course. Since the systematic first courses in the several sciences do not customarily take the work done in a general science course into consideration students often go over the same ground twice. No satisfactory solution has yet been found for this problem. Most institutions having general courses try to identify students of scientific aptitude and interest early and send them at once into introductory courses. Under this arrangement the problem of articulating general courses with advanced instruction does not exist except in the case of students whose intellectual interests change. The latter may be required to repeat in an introductory course what has already been covered in a general course. This repetition and the consequent loss of time many scientists consider unavoidable because they believe that the two types of courses have basically different goals unattainable in a course designed for both major and nonmajor students.

Professor Loud of Antioch College, for example, says:

So far as chemistry and physics are concerned, Antioch College has drawn what has been increasingly recognized by educational leaders as a valid and necessary distinction between the objectives of a course for the general student and the objectives of a course for students beginning to major in a scientific field. It is extremely dubious whether a single course can effectively attempt both sets of objectives.

Under this plan if a student takes the general course in science and then decides to major in physics or chemistry he

begins to study these subjects systematically with other students in the usual elementary courses.

Though the segregation of nonscience and science students is the most common current arrangement, some institutions have attempted to avoid penalizing those whose interest in science is so excited in a general course that they wish to take advanced instruction by supplementing the second course in science with the subject matter the student did not get in the general course. Thus by outside reading and tutoring or by special auxiliary class sessions able students keep up with their classmates who had the introductory course. In some institutions where general courses are required of all students, those who know they are going to take advanced work in science are given additional instruction simultaneously with the general course. This arrangement has worked effectively for a number of years at the University of Florida where all students take a general course in biological science composed of lectures, demonstrations, and discussions, but those who intend to major in biology or enter a medical school take in addition to the general course supplementary laboratory work in which much of the usual detailed material of the introductory course is covered. Thus the needs of both the science student and others are served without inconvenience or loss of time to either.

Another method of articulating general and advanced courses in science which will probably eventually be most satisfactory for both types of students involves a general science course for all students regardless of their special intellectual interests or their future vocations with a new form of first course in the various individual sciences for those who intend to take advanced work. This plan requires the shifting of some of the present material in the introductory courses to the general course. That is, material in physics which must be included in the general course for the education of all students will not as at present be duplicated in the first systematic course in physics. An increasing number of scientists believe this to be the ultimate solution to the problem of arranging an appropriate sequence of science courses for both the specialist and the nonmajor student. They reason that the general course if properly organized and taught should be equally valuable for both types of students. If general courses em-

phasize scientific method, the history and philosophy of science, and the impact of science on modern life, as many believe they should, then little duplication should occur, because elementary courses do not often stress these objectives. In considering the possibility of having future scientists also take a general course before beginning their special studies Professor George Glockler, head of the department of chemistry at the State University of Iowa is of the opinion that,

After eight years of teaching such a course, it appears that this type of treatment might also even serve as an introduction to the science for majors of chemistry and other professional groups. It would be well to give budding chemists an over-all idea of the field, so that they would have some basic notion why they are to study the special courses of their curricula, which must appear to them as a series of disjointed topics in chemistry. The difficulty of instituting such a plan as the creation of a beginning course in orientation in chemistry lies in the fact that there is not time to place this course into a four-year curriculum leading to the B.S. degree. A chemistry department, which is accredited by the American Chemical Society, naturally will follow the general scheme of chemical education as evolved by the chemists of the country and as administered by the Accrediting Committee of the American Chemical Society.

This problem of providing instruction for the common run of students in the various scientific fields dramatically illustrates the extent to which higher education has been organized around the interests of specialists. Although only a small fraction of the students in any elementary class expect to or will ever become specialists in that particular field, almost all the elementary instruction of the colleges is organized around the interests and needs of this small group. The eighty-five or ninety percent of students who have other intellectual interests and abilities and the thousands who leave institutions of higher education before completing a full sequence of studies have been given scant consideration in fashioning the college curriculum.

There are several things which prevent the development of adequate instruction in science for the layman. One of these is the lack of means to measure the results of instruction. New instruments of evaluation are needed (1) to assess the student's knowledge before receiving instruction, (2) to determine his progress in course, (3) to measure the results of instruction at the end, and (4) to assist in the articulation of general courses with advanced instruction. The construction of such examinations is a task of such complexity and

magnitude that few institutions of higher education can recruit and maintain the necessary staff. Some sort of co-operative effort in the making and evaluation of the tests themselves is necessary, an enterprise that should be feasible because of the fact that all programs of general education have some objectives in common. New examinations for these purposes should be geared to the broad purposes of instruction in science; they should not be concerned primarily with the measurement of the retention of factual material. They should appraise the student's understanding of scientific method, his knowledge of broad scientific principles, his ability to apply these principles in novel situations, and his comprehension of the evolution of the leading contemporary scientific ideas. The achievement of the other minor goals, which vary from institution to institution, could be determined by the use of local supplementary tests. Or a broad battery of examinations covering a wide variety of objectives might be prepared and institutions could administer such sections as were pertinent to their own particular courses. Such examinations are indispensable if faculties are to know whether the objectives of general education are being achieved.

The lack of examinations to measure the results of general education is matched by a paucity of textual materials. There are at present virtually no texts available to suit the needs of students in any of the general courses in science. Many institutions continue to use textbooks written some years ago for survey courses, because these are the only materials which cover more than one field. These texts, however, are not satisfactory for many of the newer courses, since they present too many details on many subjects and do not deal intensively enough with selected principles or topics. Textbooks for elementary courses in the sciences on the other hand, in addition to including too much detailed material, are too narrow in range.

To overcome this shortage of teaching materials teachers are using ingenious methods, one of the most common of which is a detailed outline or syllabus which not only lists the various topics to be discussed, but also supplies provocative questions or brief discussions of the problems involved. These syllabi are commonly supplemented by extensive reading lists covering relatively brief statements in journals, text-

books, popular books on science, and original scientific works when these are available in English. Mimeographed statements prepared by the staff are also in common use. It is the consensus of teachers that no textbook can be prepared which will completely supply the material needed in a course of this type. When there is more general agreement as to what these courses should contain, and how they should be organized, however, standard texts will no doubt appear containing basic materials related to important scientific generalizations or laws. Such a volume might contain several dozen leading discoveries, each forming a chapter or section in which the history of the project would be briefly traced, the methods employed in attacking the problem, the results both abortive and successful, the development of the law or generalization, its significance in the development of science, and the philosophical implications. To this some would wish to add brief biographical material on the figures responsible for the discovery. If the sections were more or less discrete units, a given teacher could select such materials as he needed and arrange them to suit his own taste. To accompany such a work a source book containing original writings on science is also greatly needed.

No discussion of courses for the nonmajor student should be completed without reference to the education of those who teach these courses, for both organization and methods are determined not by what is desirable in the abstract, but rather by what the present college teacher knows and is able to do. It may be agreed, for example, that a course embracing the subject matter of physics, chemistry, geology, and astronomy, or any combination of these subjects, should be taught by one person who has sufficient understanding of all the fields to teach them at an elementary level. But there are now few such teachers available. The policies and practices of the graduate schools prevent a broad education in science. Designed as it is to train research workers, the graduate program provides an ever-narrower training, in which the student moves further and further away from other fields of knowledge as he advances in his own. He receives little or no instruction in the history or philosophy of his subject, and no attempt is made to show the impact of scientific discoveries on modern life. Nor does graduate education pro-

vide the professional knowledge and skills which all good college teachers must possess.

The offering of adequate instruction in the various areas of knowledge for the nonspecialist student must wait upon fundamental reforms in graduate education. The enterprising teachers who are really interested in preparing young people for the common responsibilities and activities of adult life will acquire the knowledge and master the skills needed for this responsibility. Some will do this, as they have in the past, even though they must make up the deficiencies of their graduate education without material or spiritual reward and sometimes even with a loss of professional status and income. But since the number of such enterprising spirits in any profession is limited, there will not be an adequate supply of broadly educated college teachers in science until the philosophy and practice of graduate education change. There is a crying need for teachers who have studied broadly in several sciences, who understand scientific method, who know something about the history and philosophy of science, and who have acquired the elementary skills of teaching. The demand for such teachers is so great, that no imaginable output of the graduate schools could meet the requirements of the colleges in the years immediately ahead. Until these institutions give serious attention to the training of college teachers it will be difficult to develop adequate general courses in science, or in any other field.

